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GEOTHERMAL PROJECTS

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GEO-HEAT CENTER QUARTERLY BULLETIN

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A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources

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Cover: Upper Left - Federacion Thermal Spa, Argentina (photo by A. Pesce); Upper Right - ORMAT combined cycle energy convecters, Hawaii (ORMAT brochure); Lower Left - Ron Barnes with tropical cichlids, Oregon (photo by T. Clutter); and Lower Right - IFA Greenhouses rasing tree seedlings, Klamath Falls, Oregon (photo by T. Boyd)

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ADVENTURES IN THE LIFE OF A SMALL GEOTHERMAL DISTRICT HEATING PROJECT or "THE LITTLE PROJECT THAT COULD"

Dale Merrick
I'SOT Inc.
Canby CA 96015

ABSTRACT

A small community drilled a 2100-ft geothermal well to use the geothermal water for district heating. Pump test results showed a long-term production rate of 37 gpm at approximately 190EF with a pump set at 250 feet. The method of disposal is to the surface waters of a river after flowing though an activated charcoal filter to remove mercury.

This paper chronicles the three-year evolution of a small geothermal direct-use project from conception to the final stages of challenges that were faced by a small community.

More government assistance is needed to overcome drilling and environmental roadblocks for small communities willing to develop geothermal resources.

INTRODUCTION

Canby, a small town in Modoc County, California, shares many similarities to other places in the western United States (Figure 1). It is high and dry being 4300 feet above sea level, and has about 12 inches per year annual rainfall. It is predominately rural with most of the land being used for grazing livestock and growing different kinds of hay. Major employers in these areas tend to be state and federal agencies that manage public lands. Private businesses exist to serve the need of the farmers, ranchers, government employees, and travelers on their way to someplace else. But Canby, like many other small western towns, has abundant geothermal resources. The American West, still geologically active after millions of years of volcanic upheaval, has yet to realize the full potential of this valuable asset.

As the cost of energy increases over time, there will be more small communities looking at developing the geothermal reserves in their area. There is a great need for state and federal support to help courageous (I do mean courageous) communities that take on projects such as these. If the United States is serious about energy independence, federal and state governments should support geothermal development by funding initial financial and geological assessments and later, environmental permitting and drilling while continuing to support transfer of technological information through Department of Energy funded resources. Small communities do not have the kind of financial resources needed to effectively bring a geothermal project to completion, be it power generation or low-temperature space heating. Important infrastructure could be started at this level before the encroachment of asphalt and concrete that make future development cost prohibitive.

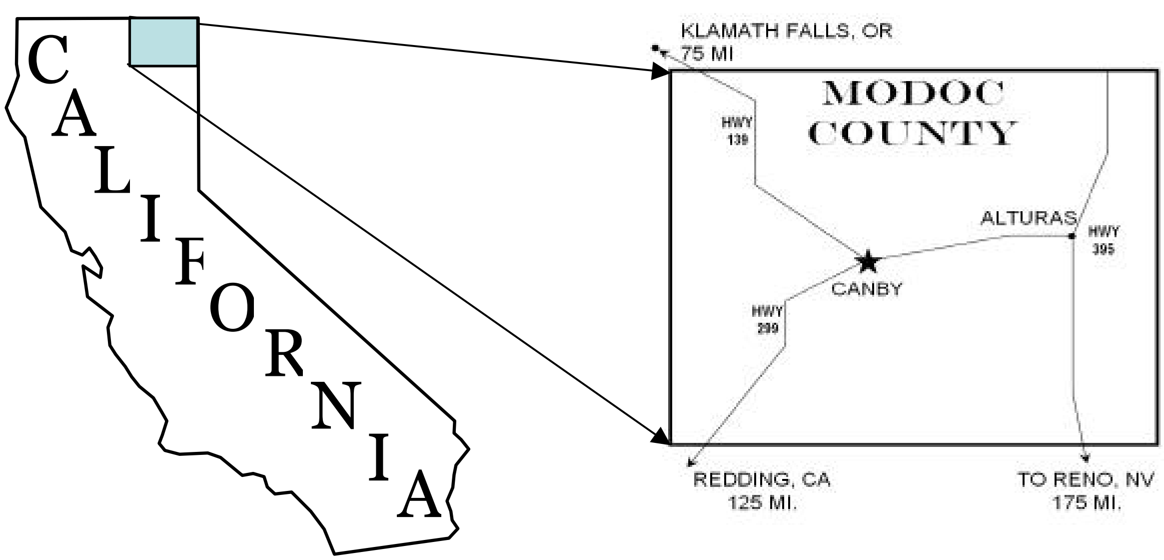

Figure 1. Location map.

A small geothermal district heating project was recently undertaken by I'SOT Inc. located in Canby. I'SOT is a society of people organized since 1969, as a community, exclusively for charitable, religious, and educational purposes within the meaning of section 501-c-3 of the Internal Revenue Code. I'SOT owns and operates a rural health clinic and low-income housing. Many I'SOT members work in a licensed 30-bed group home for juveniles. A nine-member Board of Directors voted by the membership, rotating every three years, makes community business decisions. I'SOT is an integral part of Modoc County activities including annual Children's Fair, Health Fair, and other public events. I'SOT has participated on the Modoc County Grand Jury, Hospital Board, Planning Commission, Child Protective Services, and Mental Health Committee.

I'SOT spends between $21,000-$42,000 annually in propane costs for residential space heating and domestic hot water, depending on the price of propane and the duration and harshness of the winter. While drinking 87EF tap water from our community well and having other evidence of geothermal activity in the area, it seemed that there was a possibility of reducing these energy costs.

PRELIMINARY INVESTIGATION

In May 1998, I was a civil engineering student at the Oregon Institute of Technology (OIT) and an I'SOT member, which had several advantages. As a student, I could work some of the geothermal project into my coursework for college credit and there was constant access to OIT Geo-Heat Center (GHC) expertise. Secondly, I could devote the amount of time the project demanded without worrying about income. These advantages were essential for the challenges ahead.

As the principal investigator for I'SOT Inc., I solicited the help of the GHC to determine the geothermal potential on I'SOT property. Kevin Rafferty of the GHC came to Canby and dropped a temperature probe down our community well to get the data needed to plot a temperature gradient. The gradient he found was similar to geothermal wells in the town of Alturas, twenty miles away, being 7EF/100 ft. It was estimated that at 1600 feet of depth, a water well driller would be able to find 150-200 gpm at 150E-160EF. Records of other deep wells in the area verified this possibility. A hot spring two miles away that discharges 500 gpm had very good quality water and our hydrologist believed that our well would intersect the same aquifer. Preliminary estimates were made about how much the entire project would cost and we could expect would save annually. Assuming that our resource had the anticipated flow and temperature, we expected to capture 95% of annual space heating costs. This was all encouraging news, but we didn't have the money to drill a well or establish the infrastructure for a district heating system.

The I'SOT Board of Directors decided to go forward with efforts to obtain government funding for a district heating system. The unique nature of the I'SOT community allowed for the project to be based on 100% market penetration. This is an essential difference from most communities as maximum penetration is not always achievable. Another positive aspect of the project is that concrete and asphalt have not taken over the town, keeping trenching costs to a minimum.

OBTAINING INITIAL GRANTS

In August 1998, a solicitation from the USDOE Idaho Operation Office offered a 75%-25% grant to drill an exploratory geothermal well. I'SOT proposed to drill a 1600 foot geothermal well, space heat about 53,000 ft^2 of residential housing, and create a 15-acre warm water wetland as a way to dispose of the geothermal effluent. After all, there was one two miles away that was a gathering place for all kinds of wildlife. We submitted a proposal with help from the GHC and won an award to drill our well--IF, we could get another award from the California Energy Commission (CEC) to fund material for a district heating system (Figure 2).

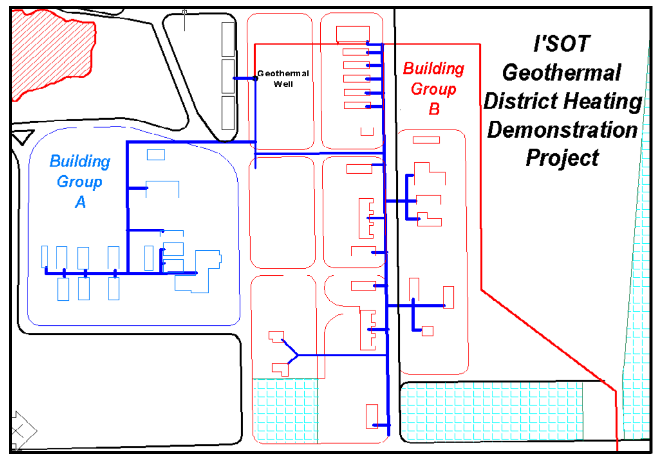

Figure 2. Proposed district heating layout.

In January 1999, a geothermal R&D solicitation from the CEC came out, but it was not particularly friendly to direct-use projects. Although I'SOT was "encouraged" to participate, we were told privately not to get our hopes up as staff recommendations no longer supported direct-use projects because of the low cost of natural gas, a situation that no longer exists. Through contacts and a little luck, we arranged a meeting with Dr. David Rohy, then Vice-chair of the CEC. It was through Dr. Rohy's support that we got a materials only award for $304,525 contingent on getting a viable geothermal resource through our partnership in the DOE drilling.

Up to this point, efforts toward our project goal were going well. We just had won two awards back to back and everything seemed like we would have our project completed within the year. Obtaining grants based on reasonable assumptions was the easy part.

PERMITTING AND THE SEARCH FOR A DRILLER

Going into this adventure, it was not clear to us exactly how much permitting was involved. The initial environmental assessment (EA) by the California Division of Oil and Gas as the lead agency was done expeditiously, beginning in July 1999 and ending in September 1999 with a Negative Declaration. The County Use Permit to drill was another matter, however, and that permit wasn't obtained until December 2000. There is a saying that the "wheels of government grind slowly." It's true. By this time, winter had set in and the time for drilling that year was gone.

We had also gotten bad news on our drilling solicitation. Out of 17 drilling companies that were sent bid packages in August 1999, only three responded with bids that were twice and three times the amount originally estimated. Several things factored into the bids being so high. First, drillers were busy and didn't need the work. Second, drilling on the Modoc Plateau is not an easy task with alternating zones of lost circulation and sticky volcanic tuff, so it has a bad reputation. Unknown to us at the time was that drilling in this area requires a larger drilling rig with the hydraulics to blast through the tuff zones. Regular water well drillers protect themselves by estimating the worst case scenario. Our drilling budget with the DOE prevented obtaining a larger drilling rig and we thought we could negotiate with a driller of good reputation and take our chances.

By January 2000, the CEC gave I'SOT a March 31st deadline to sign a driller. Even though I'SOT had started permitting two months before award, the CEC felt that I'SOT had not achieved significant progress toward our project goals.

A driller was signed on March 7, 2000, not knowing if that was good or bad news. I'SOT knew the CEC funding was safe for the time being and we hoped for the best during the drilling process that would commence the first week in April. In the initial drilling estimate, California required blow-out prevention equipment, which was not considered as we were going after 150-160 F water. It was worked out with the DOE to use all available funds to drill the well. I'SOT made plans with our consultant to supervise the drilling but be in close contact to also save money. (See GHC Quarterly Bulletin, Vol. 21, No. 4, Dec. 2000 - "Drilling Geothermal Well ISO" for details on the drilling project.)

LET THE GAMES BEGIN

I'SOT began drilling our geothermal well on April 6, 2000, which was estimated to take up to three weeks (Figure 3). It took three months. The soft volcanic tuff formations we encountered made drilling difficult. Day after day, the people in the community would ask if we were getting close. After eight weeks and no water at 1600 feet (the original estimated depth), I'SOT took a temperature log of the well and found about 160EF at 1600 feet, which verified the original estimate. Our consultant said to prepared to drill past 2100 feet. A decision was made to case the well and drill until 2000 feet.

After casing the well to 1600 feet, drilling resumed and within a week we were at a depth of 1950 feet and still in the soft tuff. Another temperature log revealed a temperature of 208EF. It was getting hotter, but still we had no water. The I'SOT hydrologist was encouraged because the cuttings were beginning to be lithified from the heat and began to look like the cuttings of another geothermal well in Alturas that was successful. Another decision was made to borrow more money and drill until we got a resource.

Figure 3. Drilling the well.

We found our resource on June 8, 2000. The drilling went to 2100 feet and a log was taken to find out what we had. The log said that the bottom-hole temperature was 223EF and an "educated" guess at the flow was somewhere about 200-300 gpm according to the technician doing the monitoring. Even if we didn't have that much water, we felt we had enough.

The big day came when the driller was going to develop the well or bring the water to the surface to find out what it would produce. We waited, and waited, and waited until we were told that the well was "plugged up" and it would cost more money to unplug it. With more borrowed money, we contracted the driller with the help of the consulting firm GeothermEx, Inc. to explore ways to solve this problem.

The first method that was used was referred to as "water stimulation;" where, water was pumped down the well at a rate of 350 gpm at 250 psi. This was done to remove any obstructions outside of the liner that was placed between 1600 and 2100 feet, and to make the aquifer possibly more productive. This method was unsuccessful.

More investigation revealed that there was sediment inside the liner up to about 1900 feet. More money was borrowed to rent a large compressor and experts to remove the sediment. By June 6, 2000, we had a resource, but it wasn't what we had expected. A pump test would have to be done by a hydrologist to determine what the long-range productivity would be.

The end of the drilling story is this: A $192,000 project ballooned to about $450,000 and a resource that was so small it was scary. You can imagine the angst the community felt after pouring all of this money into a hole in the ground (Figure 4). The DOE kicked in another $60,000 for cost overruns. In the end, a $48,000 drilling project for I'SOT ended up being around $250,000 with the DOE portion being about $204,000. The only other worse case scenario I imagined at this point was to not find anything at all.

Figure 4. The wellhead.

PENNILESS BUT HOPEFUL

After the drilling was complete, we were in hard straights financially and the last thing the Board wanted to hear was that another $11,000 was needed for a long-term pump test and a hydrologist report. This was needed to verify to the CEC that we had a viable resource. In September, the I'SOT Board of Directors approved the funds and the results were given to the GHC for analysis in October.

The hydrologists report showed a long-term productivity rate of 37 gpm at about 180-190EF. Such a small resource for so much money we thought. However, the GHC report said, "*it remains possible, provided careful design, to capture virtually all of the anticipated space heating savings.*" We were encouraged by the report, but something else was beginning to change our original plans.

WATER QUALITY AND THE CALIFORNIA TOXIC RULE

Although the water chemistry seemed to be good, the arsenic concentration was about 95 µg/L which is above the drinking water standard. And even though we are not drinking the water and the hot springs two miles away grows fish in the same water, we now have a disposal problem. The Central Valley Regional Water Quality Control Board (CVRWQCB) now suggested that we plan to dispose to the Pit River one mile away. The proposed wetland that we had wanted to develop was now, for all practical purposes, impossible. To do a wetland now meant that we had to drill monitoring wells around the perimeter of the wetland and monitor monthly. If the arsenic concentration increased in the local groundwater, we would have to shut down. The CVRWQCB was positive this would occur. The decision was made to dispose to surface waters of the Pit River.

This created a problem for the CEC. They felt it was a change of scope to change disposal to surface waters. After spending close to $450,000 to drill for a resource, this was not acceptable to I'SOT. I'SOT assembled a geothermal expert, a regulator and a staffer from our State Senator's office, along with I'SOT representatives for a meeting with the CEC that brought positive results. I'SOT and the CEC would work together toward a no-cost time extension, as a time consuming National Pollutant Discharge Elimination System (NPDES) discharge permit would now be needed.

To add to our dilemma, California had recently adopted more stringent water quality regulations as contained in the California Toxic Rule (CTR). The maximum concentration for arsenic was lowered from 50 µ/L to 10 µ/L. We began taking samples of our effluent. CTR testing began which tests for every known pollutant in two different seasons, winter, and summer. About $16,000 was spent on pump tests and CTR testing. I'SOT also was in the unfortunate position of being the first discharger to go under the new CTR regulations. This meant that everything had to be done by the book, and more. The CVRWQCB didn't want the embarrassment of not doing their first NPDES permit under the CTR discharge correctly.

The CVRWQCB also needed a licensed hydrologist to do a mixing zone study to determine dilution credits. This $1,500 report was done along with learning a computer modeling software developed by Cornell, available through the USEPA, to model the mixing characteristics of our effluent. The results of the hydrologist report and the CORMIX modeling helped the CVRWQCB define a mixing zone.

An injection well would have eliminated the needed of all the environmental permitting to come, but at an additional expense of $350,000+.

WATER QUALITY AND THE M-WORD

In January 2001, I met with a representative of the CVRWQCB at our well site and we grabbed a sample of effluent from the wellbore (static water level is 20 feet). It was an ugly, cloudy sample, but we tested it for low-level mercury. The sample only had a concentration of 7 ng/L. In August 2001, at the end of our CTR testing, the regulator decided to check one more time for mercury; only, this time the concentration was 120 ng/L--over six times the traditional EPA aquatic threshold. I'SOT felt that the number was high because the sampler did not follow the strict protocol necessary for ultra-clean sampling. We sent several samples to Frontier Geosciences of Seattle, a leader in mercury research. Results confirmed that I'SOT now had a mercury problem.

The CEC became more nervous by the day because there have been other geothermal projects shut down in Modoc County because of mercury. This was one more place that the CEC became uneasy about the I'SOT project, but in this case with good reason.

It was now September 2001 and a way to mitigate the mercury problem was necessary to save the project. I'SOT sent several gallons of our effluent to Frontier for mercury removal experiments costing $4,000. The lab told us that activated carbon (AC) may work for but wanted to set up a pilot optimization study for another $10,000 and then make a recommendation. Also, for a price of $150,000, Frontier would design an AC system that would mitigate the mercury to under 10 ng/L. This was not an option.

This price was not an option, but maybe the process was. I'SOT mirrored an experiment that Frontier did at Basic Labs of Redding and found that AC removed 99% of the mercury on our effluent. We also did another $4,000 experiment that modeled the detention time of a commercial granular activated carbon (GAC) from USFilter with the same results (Figure 5). Interestingly, industry has very little data on mercury removal from geothermal water with GAC and our data is of interest to USFilter. These experiments were essential to get our NPDES discharge permit.

All agreed, except for the USFWS, that our small discharge and extraordinary mitigation measures were no measurable threat to the Pit River or to the creatures that populate it. It was also unfortunate that I'SOT had to agree to $5,000 more effluent monitoring in the first six months of operation in order for the USFWS not to contest our discharge permit. The U.S. Environmental Protection Agency (USEPA) wrote a letter stating that the effluent monitoring for our project was excessive and recommended reduction after the first year.

Figure 5. Activated carbon filter.

With the CTR sampling done, the mercury mitigation looking promising and the support of the USEPA, CVRWQCB, Modoc County, and California Department of Fish and Game, I'SOT obtained a NPDES discharge permit on April 29, 2002.

ADD ANOTHER FUNDING AGENCY, AND STIR

As if there wasn't enough uncertainty already, in January 2001, the National Renewable Energy Laboratory (NREL), a DOE funded lab, sent out a 50-50 cost-share, direct-use solicitation that offered to fund permitting, engineering, and installation in two phases for selected projects. This was an opportunity to match $304,525 in CEC materials-only funding. It would also be a juggling act to start doing business with NREL and CEC as the agencies have different reporting, engineering, funding requirements, and construction time lines.

Nevertheless, a proposal was written in February 2001 to answer the NREL solicitation for Phase I funding that would pay for engineering a district heating system that would otherwise be paid by I'SOT. We initially had difficulty giving NREL the kind of proposal they were expecting because we had only answered solicitations for grants before and now we were trying to do one for a contract. Although our project was still evolving because of water quality issues, the NREL staff was very patient and with their support, finally entered a Phase I contract in January 2002. If I'SOT were to enter a Phase II contract with NREL for installation, we would be required to furnish them with two years of data, monitoring, and limited technology transfer.

Entering into the construction phase of the project with a federal program, however, presents even more environmental paperwork and delay. Even though all environmental requirements were satisfied to receive state funds, the federal government requires NREL to complete a separate environmental review before disbursing federal money. At this writing, a decision has yet to be made about whether to receive federal funds to construct the project.

CONCLUSIONS

Although the I'SOT Geothermal Project has experienced probably every issue that can be faced on a small project, it is important to note that most of the agencies mentioned in this paper have been as accommodating as possible to help forward this project.

The employees of the CVRWQCB, California Department of Fish and Game, and the USEPA were all very helpful; although, they are themselves enmeshed in ever-changing environmental regulations that are many times political, sometimes scientific, and always conflicting. It is hoped that the future of the environmental regulation takes a more holistic approach to projects rather than it does at present.

Finally, it takes community support, both financial and moral, to develop a direct-use geothermal project. Most projects that fail, fail because the community involved doesn't have the time, cohesiveness, tenaciousness, or courage it takes to follow through to the end. Those are properties of a community that cannot be imposed on by government, but must come from within the community itself. If a funding agency is fortunate enough to find a group of people as described, they should do what ever is necessary in the way of support. These partnerships can serve as examples of what can be done when government agencies and the public working together to build tomorrow.

OUT OF AFRICA

Aquaculturist Ron Barnes Uses Geothermal Water in Southern Oregon to Rear Tropical Fish from African Rift Lake

Ted Clutter
Geothermal Resources Council
Davis, CA

Figure 1. ***Overview of the 72 15 ft x 100 ft fish ponds near Klamath Falls, OR.***

In the harsh temperate climate of southern Oregon, colorful tropical fish from Africa thriving in outdoor ponds are the platform for a successful aquaculture operation—with the help of geothermal waters. Ron Barnes is the energy-wise entrepreneur who is tapping this abundant local resource, commercially breeding thousands of these prized animals for the specialty tropical fish market on the U.S. West Coast and beyond.

A seasoned fisheries expert, Barnes earned a bachelor of science degree in marine biology from the University of California, Santa Barbara, and a masters in aquaculture from University of California Davis. He started out wholesaling tropical fish in Santa Cruz, CA, in 1988, before buying a small—and remote—tropical fish hatchery in 1990. "For me, the operation had a lot of appeal, with room to grow, and especially for its geothermal water," says Barnes.

Located near Merrill in the Lower Klamath Valley (about 10 miles south of Klamath Falls), the hatchery's ponds that Barnes bought are heated with geothermal water that first heat greenhouses at Liskey Farms, Inc. The greenhouse complex consists of four 6,000 square-foot buildings for growing bedding plants and perennials. At peak use, the 1.5-acre greenhouses complex uses 400 gallons per minute (gpm) from six geothermal wells ranging in temperature from 80° to 200°F.

From a 14,000-gallon steel tank salvaged from a railroad car buried atop a hill overlooking the greenhouses, water arrives at the greenhouses at 180° to 185°F. Depending on outside temperature, the water leaves the greenhouses at between 165° and 185°C. Effluent greenhouse heating water is piped to Barnes' original ponds, located adjacent to the greenhouses.

Barnes negotiated leases for the ponds and for purchase of geothermal water from the Liskey greenhouse operation. After getting his feet wet in the business for the first year, he bought 80 acres of land across the road from his original operation, with an established geothermal well. Today, Barnes' operation claims 72 ponds, with 37 located at Liskey Farms, and an additional 35 on Barnes' property across the road.

Breeding stock for the mbuna, peacock and haplochromis cichlids that Barnes raises for market came directly from Lake Malawi, a fascinating and unique biosphere located in the East Africa's Great Rift Valley. For 3,500 miles along the continent's eastern coast, stretching and cracking of the Earth's crust created a legacy of volcanic deposition that formed highlands and enormous troughs. The region hosts numerous geothermal hot springs and fumaroles, and a number of some of the world's largest lakes, including Malawi.

Figure 2. ***A typical 2" to 4'"blue zebra cichlid.***

On a smaller scale, the geology of the East African Rift System where Barnes' fish originated is similar to that of the Klamath Basin in southern Oregon where his breeding operation is located. Like the Great Rift in Africa, the area's geologic structure was formed by stretching of the earth's crust, forming large lake basins—including Upper Klamath Lake, the area's body of water (65,000 acres). Numerous fault blocks thrust up through ancient lake sediments, providing conduits for geothermal water to the surface.

Barnes' fish farm and geothermal wells are located on the flanks of one of these blocks, overlooking the former Lower Klamath Lake, which was essentially drained by irrigation projects in the first half of the 20th century. Some past lake areas are now used for agriculture, while other marshy portions are part of the Klamath Wildlife Refuge—a migration and nesting area for aquatic birds that sometimes zero in on Barnes' ponds for an easy, colorful meal. But he downplays the problem. "Most of the birds that cause trouble are migratory," says Barnes, "and there is someone here almost all the time keeps the birds away."

The operation's geothermal well pumps 300 gpm from 160 feet (Barnes' permit allows 400 gpm). Like the system at Liskey Farms, the operation employs a 14,000-gallon steel tank salvaged from a railroad car for fluid storage and to provide head for no-cost water delivery to rows of fish ponds below. The 100-foot long, 15-foot wide ponds are lined with diatomaceous earth, and are four feet deep. They are set in rows fed with geothermal water from a header pipe distribution system.

In raising tropical fish, water temperature is a key factor in success. Water from Barnes' 210EF well is 197E as it enters each pond via 1 ½" plastic pipe. It quickly mixes with the pond water, causing no harm to the fish, and levels out pond temperatures to an ideal range around 80EF. Barnes experimented with thermostatically controlled valves, but malfunctions overheated the ponds and killed valuable fish. Now he uses manually operated valves that service each pond, maintaining the ponds within a safe, 10E range of the desired 80E temperature.

Figure 3. ***Ron Barnes on top of the 14,000-gallon steel storage tank salvaged from a railroad car.***

The chemical composition of Lake Malawi's water is alkaline, with pH running from 7.8 to 8.5. Fortunately for Barnes' operation, he says, "The water in Lake Malawi is very similar to the water we get from our geothermal wells." Alkalinity is pH 8.8 out of his well, but the chemical composition of pond liners (diatomaceous earth) and soil surrounding the ponds reduce pH to about 7.5 as the water flows through the system. Though this is at the low end of that found in Lake Malawi, Barnes' fish thrive without the use of expensive chemical additives.

Barnes raises more than 100 different varieties of fish, including cichlids from Central America that also thrive in his alkaline geothermal water. He stocks no more than three species per pond to prevent interbreeding. Minnow traps are used to catch the bulk of the two-inch fish he sells, while a seine is used to catch larger fish and brood stock. Barnes and assistant Pete Booth perform all necessary chores at the year-round breeding and growing facilities.

The State of Oregon regulates Barnes' fish farm like any other agricultural operation. "To protect indigenous fish populations, the fish and game department does not allow me to raise any species of fish not native to the area that might survive if released into the wild," he explains. Obviously, tropical fish from Lake Malawi cannot survive the harsh winters of southern Oregon, and Barnes' geothermal water system commingles pond outflows with 200EF water, effectively killing living creature that might escape. The water's final destination is a cooling pond (with no outlet) that is used for stock watering.

Figure 4. ***Yellow and black bumblebee cichlids.***

Figure 5. ***Netting the larger breeding stock (6" to 8") with a two-person seine.***

Energy savings garnered by using geothermal water has been the key to Barnes' success in this often difficult business. According to Geo-Heat Center (Oregon Institute of Technology) calculations, at a peak of 300 gallons per minute and a 10E temperature loss from the well to the ponds, Barnes uses approximately 1.5 million Btus of heat energy per hour. Heating his ponds on an annual basis of 6.6 billion Btus (calculated on well use for six months), Barnes avoids the use of two million kilowatt-hours in electricity every year. That's a savings of $100,000 (at current local rate of 5 cents/kWh)!

Barnes' tropical fish farm near Klamath Falls, OR, is a perfect example of cascaded direct use of geothermal waters. With energy savings realized by using this inexpensive source of heated water, and his choice of raising high-value tropical fish, he has successfully met the marketplace. Barnes cost-effectively offers 250,000 Malawi cichlids (3" to 4") per year to tropical fish wholesalers from Portland, OR, to San Francisco, and beyond by truck and air freight.

As Barnes looks out over his operation, he sees the future. "To better utilize the geothermal resource on the property," he says, "we plan to drill an additional well this summer to expand our operations." Developed under a multi-agency Oregon government grant, the well will employ a heat exchanger loop to reheat water from his existing ponds, which will then flow to large fiberglass tanks for raising tilapia, another variety of African cichlid. Barnes will offer this popular food fish as "meat for market," dressed and frozen on site for shipment to wholesalers and restaurants.

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REFERENCES

Dicken, S. N. and E. F. Dicken, 1985. *The Legacy of Ancient Lake Modoc: A Historical Geography of the Klamath Lake Basin.* Shaw Historical Library.

Hurburt, A., 2000. "Something's Fishy on the Lower Klamath." *Herald and News* (Klamath Falls, OR, newspaper), May 17, 2000, Sec. B1, pp. 1 and 3.

Konings, A., 1997. "The Natural Environment," *Malawi Cichlids.* Back to Nature Guide, Fohrman Aquaristik GmbH, Lauenau, Germany, pp. 8-12.

Lund, J. W., 1983. *Geology of the Klamath Basin, Oregon*, Geo-Heat Center, Klamath Falls, OR.

Lund, J., 1994. "Agriculture & Aquaculture, Cascading the Geothermal Way." *GHC Bulletin*, November 1994, pp. 7-9.

Stager, C., 1990. Africa's Great Rift, *National Geographic.* 177, No. 5, pp. 2-41.

NEW GREENHOUSES IN KLAMATH FALLS

John W. Lund
Geo-Heat Center

A state-of-the-art 50,000-sq ft greenhouse, heated by geothermal energy, was recently put into operation in Klamath Falls, Oregon (Figure 1). The greenhouse, which uses technology that has long helped Canada dominate the market for tree seedlings is operated by IFA Nurseries, Inc., based in Canby, Oregon. The facility can raise about two million seedlings of ponderosa pine, Douglas fir, hemlock and other species, depending upon the demand of customers. Eventually, they plan to have four greenhouses in operation, producing about eight million seedlings a year. A second greenhouse is currently under construction and will be ready for use this fall (Figure 2).

Figure 1. ***50,000-sq ft greenhouse currently in operation.***

Figure 2. ***The second greenhouse under construction.***

The operation was located in Klamath Falls to take advantage of the geothermal heat available from the city's district heating system. To attract the business, the city of Klamath Falls extended their hot water pipeline from the downtown to the greenhouse, located on the edge of town near the South 6th street overpass and city maintenance yard. The heated water is provided from the supply side of the district heating system (see Brown, 1999) at 180°F, and the spent water is then piped to the return side of the district heating loop. A plate heat exchanger (Figure 3) transfers the heat to a secondary loop using a water-glycol mixture (Figure 4). This loop then provides heat to a series of under-bench fan coils and hot air plastic distribution tubes (Figure 5). IFA pays the city for the heat at a rate somewhat less than the corresponding natural gas rate, which does not fluctuate with the market.

Figure 3. ***The main plate heat exchanger.***

The seedlings, growing in long rows of Styrofoam containers (Figure 6), are watered by long wands that slide across the ceiling. A computer controls the heat supply, watering, lights and ventilation through opening and closing perimeter curtains and vents in the roof. Controlled lighting and uniform temperatures help the growth rate, as what normally would take a year to grow in normal light, grows in six months in this controlled environment. In addition, seedlings grown indoors in containers usually survive transplanting better than those from outdoor nurseries; where, they are uprooted for shipping. Typically, about 98 percent of the seedlings grown in the nursery's Styrofoam containers survive transplant. The customers include Boise, Sierra Pacific and Roseburg Forest Products, for planting in California, Oregon, Nevada and Idaho.

Figure 4. Secondary distribution system being installed for the new greenhouse.

Figure 5. Under-bench heating system.

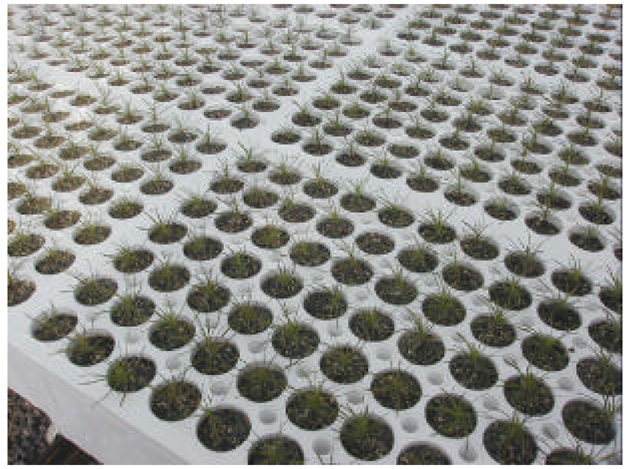

Figure 6. Tree seedlings in Styrofoam containers

ACKNOWLEDGMENTS

Material for this article is based on personal interviews with the manager Charlie Patton, and from an article in the *Oregonian* newspaper (Milstein, 2002).

REFERENCES

Brown, Brian, 1999. "Klamath Falls Geothermal District Heating System," *Geo-Heat Center Quarterly Bulletin*, Vol. 20, No. 1 (March), Klamath Falls, OR, pp. 5-9.

Milstein, Michael, 2002. "Seedlings Get a Jump-Start in High-Tech Greenhouse," *Oregonian*, Wednesday, May 22, Portland, OR, p. B1-2.

HAWAII AND GEOTHERMAL WHAT HAS BEEN HAPPENING?

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INTRODUCTION

The Hawaiian Islands lie above a geological "hot spot" in the earth's mantle that has been volcanically active for the past 70 million years, with the island of Hawaii (the "Big Island") having the most recent activity. The Big Island has an obvious, large potential for geothermal energy resources, both for electrical generation and direct utilization. Since the 1976 drilling of the HGP-A well and the discovery of the Kapoho Geothermal Reservoir in the lower Kilauea East Rift Zone, geothermal power potential on the Big Island has been estimated at between 500 and 700 Megawatts (Thomas, 1987).

As a historical note, King Kalakaua, who was on the throne of the Hawaiian Kingdom before Hawaii became a state, had extraordinary vision regarding many things, including electricity. Kalakaua, along with several of his closest advisors, visited Thomas A. Edison in New York in 1881 because the King was interested in replacing the kerosene lamps being used at his Iolani Palace with electric lamps. Because of his efforts, Honolulu became one of the first cities in the West to have electric street lights when Princess Kaiulani closed the switch that provided the power, not from the volcano, but from a nearby hydroelectric plant (Energy, Resources, and Technology Division, 2002d).

GEOTHERMAL RESOURCES (Thomas, 1984 and 1985)

Geothermal interest was motivated by the fact that imported oil is used to supply over 90 percent of Hawaii's energy needs. No other state in the U.S. is so critically dependent on imported oil. Obviously, geothermal was originally regarded as a renewable source to help make the islands less dependent on imported energy.

The Hawaii Geothermal Resources Assessment Program was initiated in 1978. The preliminary phase of this effort identified 20 Potential Geothermal Resource Areas (PGRAs) using available geological, geochemical and geophysical data. Figure 1 shows a map of the major islands of Hawaii and the location of the 20 PGRAs. The second phase of the Assessment Program undertook a series of field studies, utilizing a variety of geothermal exploration techniques, in an effort to confirm the presence of thermal anomalies in the identified PGRAs and, if confirmed, also more completely characterize them. A total of 15 PGRAs on four of the five major islands in the Hawaiian chain was subject to at least a preliminary field analysis. The remaining five were not considered to have sufficient resource potential to warrant study under the personnel and budget constraints of the program.

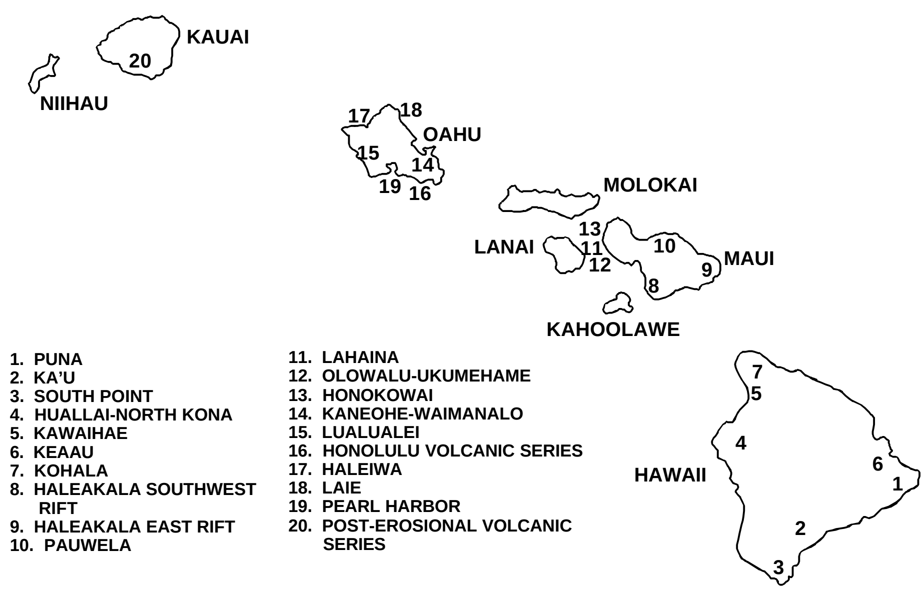

Figure 1. ***Map of the major islands of Hawaii showing the location of the 20 Potential Geothermal Resource Areas (PGRAs) (Thomas, 1984).***

The island of Kauai is the northernmost and oldest major island of the Hawaiian chain. It is made up of a single volcanic shield that completed its most active stage of volcanism nearly 3.3 million years ago. It was not studied during this phase, due to the absence of significant geochemical or geophysical indications of a geothermal resource. The great age of volcanism on this island would further suggest that should a thermal resource be present, it would be of low temperature. The probability of a viable geothermal resource of even a moderate temperature (less than 100ºC) existing on Kauai is believed to be 5% or less. It is nonetheless noteworthy that test holes drilled for groundwater exploration in the Lihue area during the 1990's did encounter warm (~30ºC), slightly brackish groundwater.

The island of Oahu, the major population center of Hawaii including Honolulu with a total population of 876,000 and area of 1,550 km^2, is the second oldest major island and was formed from two independent volcanic systems. A preliminary assessment identified six locations where available data suggested that a thermal resource might be present. The present assessment of the geothermal potential for Lualualei Valley is that there is a 10 to 20% probability of a low-to-moderate temperature resource existing at depths of less than 3 km. The probability of the existence of a moderate-to-high temperature thermal resource within 3 km is less than 5%. The potential for geothermal in Mokapu Peninsula is less than 5% for a low-to-moderate temperature system at a depth less than 3 km. The assessment for Koolau Caldera is less than 10% for a low-to-moderate temperature geothermal system less than 3 km deep. The probability of a high temperature system at these depths is less than 5%. The potential of geothermal system within a depth of 3 km for other PGRAs located on Oahu is considered very unlikely.

The island of Molokai is the smallest of the major islands and was formed principally from two volcanoes. Due to the anticipated small demand for geothermal power on the island of Molokai in the foreseeable future, only preliminary efforts were made to assess the potential for a resource on this island.

Maui is the second largest and second youngest island and is made up of two independent volcanic systems. The preliminary assessment surveys indicated six locations that might have a potential for geothermal resources. Of the three located on West Maui only one has a potential greater than 5% for a low-to-moderate geothermal system. The Olowalu-Ukumehame Canyon was assessed at having a 60 to 70% probability of having a low-to-moderate resource and a less than 10% probability of having a moderate-to-high temperature resource. The other three PGRAs are located on Haleakala Volcano. Only two of them showed significant findings of a geothermal resource. The Northwest Rift Zone has a probability of 10 to 20% for a low-to-moderate temperature resource and less than 5% probability for a moderate-to-high temperature resource. The Southwest Riff Zone has a greater probability at 30 to 40% for a low-to moderate temperature resource and 15 to 25% for a moderate-to-high temperature resource.

The island of Hawaii, with a population of 148,700 and an area of 10,400 km^2, is the youngest and the largest island in the Hawaiian chain that is made up of at least five volcanic systems. Figure 2 shows the major rift zones and calderas of each volcano on the island of Hawaii. Seven locations were identified as PGRAs in the preliminary assessment. One PGRA, the Kilauea East Rift Zone, was later designated as a Known Geothermal Resource Area (KGRA) due to the discovery of a productive geothermal well. The probability of a geothermal resource in this area is 100%. The Kilauea area also includes the Southwest Rift Zone that has a geothermal resource probability of 100% for a low-to-moderate temperature resource and 70 to 80% for a moderate-to high temperature resource within 3 km of depth. The Mauna Loa area did not exhibit any significant indications of a geothermal resource; therefore, the probability of a geothermal resource is less than 5% for a low-temperature resource. The probability of a low-to-moderate temperature resource existing in the Kawaihae area is 35 to 45% and the probability of a moderate to high temperature resource is less than 15%. The upper flanks or summit of Hualalai indicated a probability of a low-to-moderate temperature geothermal resource at 35 to 45% and the probability of a moderate-to-high temperature resource at 20 to 30%.

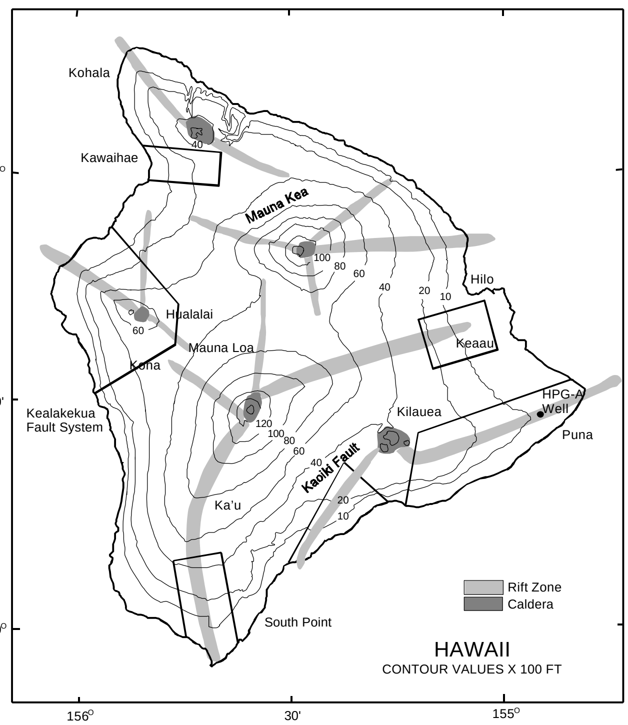

Figure 2. ***Map of the island of Hawaii showing the major rift zones and calderas of each volcano (Thomas, 1984).***

COMMUNITY GEOTHERMAL TECHNOLOGY PROGRAM (Gill-Beck, 1988 and 1990)

In 1976, a public-private partnership developed the well HGP-A in the lower Kilauea East Rift Zone on the southeast side of the island. At the time it was drilled, it was recognized as one of the hottest wells in the world. It had a bottom hole temperature of 676ºF (358ºC), a depth of 6,450 ft (1,966 m) and it produced 80,000 lb/hr (36.3 tonnes/hr) of a mixed fluid (57% liquid and 43% steam). The surface temperature during production was 365ºF (186ºC).

An experimental 3 MW power plant went online in 1982; which, when it was shut down after eight years of production, had an availability factor of 95%. The plant was originally designed as a two-year demonstration project and incorporated several unique characteristics. Because the facility was located in the Kilauea East Rift Zone and therefore, was in a high lava hazard zone, the turbine-generator set was built on skids, and the building housing the turbine-generator had a bridge crane capable of lifting the turbine-generator unit, so that it could be quickly removed in the event of a lava flow. In addition, the well was housed in a concrete bunker that could be completely enclosed with a set of covers, to allow a lava flow to cover the site without damaging the wellhead. Over the life of the plant, the generator facility produced between 15 and 19 million kilowatt-hours of electricity per year. In 1986 the HGP-A facility was transferred from USDOE (U.S. Department of Energy) ownership to the state of Hawaii and assigned to the Natural Energy Laboratory of Hawaii.

Figure 3. The HGP-A power plant showing the generator and turbine set inside the building (Lund, 1985).

In 1985, the Noi'i O Puna (Puna Geothermal Research Center) was dedicated adjacent to the power plant. It was established to support direct use of the unutilized heat from the brines of the HGP-A well. The Community Geothermal Technology Program (CGTP) was conceived in 1986. The purpose of the program was to support small business enterprises in the Puna District, encourage the use of waste heat and byproducts from HGP-A, and to allow access to the geothermal resource.

Figure 4. Blessing of HGP-A facility by a local Hawaiian minister at the transfer ceremony. Dr. John Shupe, one of the major promoters of HGP-A is standing on the far right (Gill-Beck, 1986).

Figure 5. Governor George Ariyoshi speaking at the dedication of Noi'i O Puna Laboratory (Gill-Beck, 1985).

There were two rounds of small grants offered, through the CGTP, to entrepreneurs in 1986 and 1988. The first round awarded grants for five projects. They were 1) Green Papaya Powder Drying, 2) Bottom Heating System using Geothermal Power for Propagation, 3) Experimental Lumber Drying Kiln, 4) Hawaii Glass Project, and 5) Cloth Dyeing by Geothermal Steam. The second round also awarded five grants which included 1) a continuation of the Bottom Heat Project, 2) Geothermal Aquaculture Project, 3) Silica Bronze, 4) Media Steam Sterilization and Drying, and 5) Electrodepostion of Minerals in Geothermal Brine. A brief summary of each project follows.

The Green Papaya Powder Drying Project looked at converting an existing fruit product processing business from electric to geothermal heat. This grant included the building and testing of a drying cabinet and production of dried fruit products such as papaya, banana and pineapple slices.

The Bottom Heating System Using Geothermal Power Project was also another proposal to convert an existing system to geothermal. This was a demonstration to see if it was feasible to heat a greenhouse using a bottom heating system which circulates hot water beneath flats of sprouting plants. The soil being warmed by the hot water facilitates the germination and growth of certain plants. Figure 6 shows Ornamental palms in the experimental greenhouse. It was founded that the rate of germination of some species improved as much as ten times during the project.

Figure 6. ***Ornamental palms in the experimental greenhouse during the Bottom Heating System Project (Camera Hawaii, Inc., 1987).***

The Experimental Lumber Drying Kiln Project proposed to design a kiln and totally automate it. There was limited commercial lumber kiln space on the island of Hawaii, so this project was proposed to reduce the need for shipping the lumber out of state for kiln drying or air drying locally which can take up to a year. Even though the heat exchanger design produced lower temperatures than the optimal temperature of 140ºF (60ºC), they were able to produce satisfactory results repeatedly after four and eight weeks of operation.

The Hawaii Glass Project was proposed to use the silica produced by HGP-A well. This was a waste product from the well that dries to a powder in the brine percolation ponds. A unique glass formula was devised using the silica and the formula was 93% of indigenous Hawaii origin. The project was not anticipated to result in a commercial glass jar or bottle making company since the amount of silica would be insufficient for a full-scale facility.

The Cloth Dyeing by Geothermal Steam Project was proposed to see if it was viable to transfer a business from Iwate Prefecture, Japan to Hawaii. The proposers found the colors were more colorful in Hawaii than in Iwate due to the chemical composition of the steam. Figure 7 shows samples of the hand-dyed silk treated with the raw geothermal steam. The dyed fabric received high grades for steadfastness and permanency. This is the only project in the first round of grants that used raw steam.

Figure 7. ***Samples of the hand-dyed silk treated with raw geothermal steam (Camera Hawaii, Inc., 1987).***

The Geothermal Aquaculture Project investigated the potential of initiating a business to sell turn-key, small-scale aquacutlure systems, as well as demonstrating the value of geothermal heated water. Tilapia was selected for the initial experiment. The tanks of simple construction used a low-input, recirculating system with a biofilter to allow a high density population. Even though Hawaii has fairly mild and uniform temperatures (20 to 30^{0}C), output can be approximately doubled using the constant temperature geothermal resource.

The Media Steam Sterilization and Drying Project proposal consisted of applying geothermal steam to shredded, local materials such as coconut husks to develop a sterile growing media. To prevent the spread of diseases carried by soil organisms, a nursery export business requires pasteurized growing media. Peat moss was the media that was imported at the time. Replacing the peat moss with an indigenous product would benefit the entire industry.

The Silica Bronze project proposed using the silica brine from the disposal ponds as a refractory material used in casting bronze artwork. The silica has been imported to Hawaii in bulk. If the silica can be recovered from the silica pond, washed and dried it may prove to be suitable for refractory use. Part of the project was concerned with developing simple ways to recover the silica from the ponds, wash it, and dry it so would be in the proper form suitable for refractory use.

The Electrodepostion of Minerals in Geothermal Brine research project was aimed at determining the nature and possible utility of minerals deposited from the hot fluid. Past research has indicated that calcium carbonate can be successfully taken from seawater. Possible future commercial applications of the deposited materials made this an intriguing bench-scale research project.

There was significant interest in the direct use of geothermal energy. Some additional proposed applications which were not funded by the CGTP include: Fruit fly disinfestation, Refrigeration, Spas, Cement Formula, Curing, Distillation, Electricity, and Polystyrene Expansion.

The HGP-A power plant was closed in late 1989 on the order of Governor John Waihee and County of Hawaii Planning Director Duane Kanuha. The closure of the power plant was permanent due to the fact that it was no longer accomplishing it's primary goal of demonstrating the benefits of geothermal power. Although the facility was designed for only a two-year demonstration life, it has been operated for nearly eight years. During the interval, inadequate maintenance had taken a severe toll on the reliability and effectiveness of the equipment, and the costs of operation exceeded the revenues being produced by the power generated. In addition, the effluent abatement systems and the brine disposal processes were neither efficient nor acceptable to the community or the regulatory agencies.

Despite the difficulties that were encountered, the facility accomplished a great deal. It demonstrated that the resource in the Kilauea Lower East Rift Zone was robust: the decline in production from the HGP-A well, over the eight year life of the plant, was only a few percent per year. The facility demonstrated that the reservoir fluids required special handling and maintenance, but also demonstrated that fluid chemistry issues could be managed. Some of the techniques for fluid handling and disposal that were developed and tested at the HGP-A facility were employed by the subsequent commercial power plant and proved key to disposal of their waste fluids. And, finally, the operations, and missteps, taken at the HGP-A facility, served to sensitize Hawaii's regulatory agencies to issues regarding geothermal development that affect the community. It should also be noted that, with the closure of the power generation activities at the HGP-A, the Community Geothermal Technology Program also was terminated due to loss of the waste heat produced by the generation process

GEOTHERMAL/INTERISLAND TRANSMISSION PROJECT (Fesmire and Richardson, 1990; Bonnet, 1990)

From 1982 through early 1990, an engineering feasibility project was undertaken to evaluate the technical and economic challenges of installing a large-scale 500-megawatt geothermal/interisland submarine cable. About $26 million (Federal and State funding) was expended in studies, design, engineering, fabrication, and testing for the Hawaii Deep Water Cable Project. Figure 8 shows the proposed route for the Hawaii Deep Water Cable. The design criteria stated that the cable(s) would have to be able to withstand the stresses of at-sea deployment (including strong currents, large waves, and strong winds), the undersea environment (including corrosion and abrasion), and be able to reliably conduct electricity for thirty years. Since the Alenuihaha Channel is nearly 2,000 meters deep, both deployment (laying of the cables) and operating environment posed unique engineering challenges.

The rationale for the project was that the primary source of geothermal energy was on the island of Hawaii, and the major electrical load was on the island of Oahu, where Honolulu is located. The scheme under consideration was to use the geothermal energy to generate power and transmit it to Oahu. At the time it was estimated that up to 500 MW could be used on Oahu, whereas only about 100 MW were needed on the Big Island.

The electricity produced by the project could potentially represent a large portion of the electric power supply for Oahu. Thus, the project would have to provide a reliable supply of electricity. The amount of energy that HECO (Hawaiian Electric Company) would purchase would be dependent on HECO's assessment of the reliability of the project and the availability of the electricity.

Two large-scale tests were conducted to examine the technical feasibility of the Hawaii Deep Water Cable. The first was the laboratory test where the cable was subjected to the electrical and mechanical loads expected during the 30 years of service. Second, the at-sea tests examined the ability of the projected, integrated control system to place the cable at the bottom accurately and to control the residual tension.

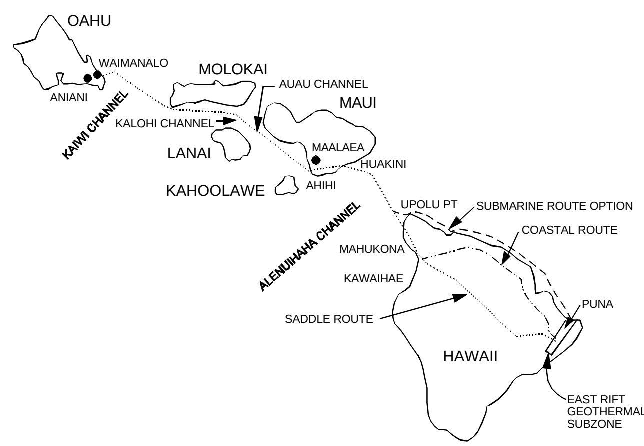

Figure 8. The Hawaii Geothermal/Interisland Submarine Cable Project Proposed Route (Fesmire and Richardson, 1990).

Over 251 different cable designs were considered. The cable tested was a double armored, paper insulated, oil filled cable designed to operate at 300 kV and transmit 250 MW of power. The cable, Pirelli Cable Design No. 116, used in the test is shown in Figure 9.

The scheme of the tests was as follows: one set of tests (the individual tests) subjected cable samples to either single worst-case loads or to loads needed to measure a characteristic of the cable; the second set (the sequence tests) subjected cable samples to a sequence of loads that duplicated the loads the cable would experience during the laying and operating for 30 years on the most hostile part of the route. Upon completion of the sequence tests, the cable sample was subjected to electrical tests. By comparing the results of this test with the results of an identical test run earlier on a new piece of cable, the effects of the sequence of mechanical loads on the electrical performance could be assessed.

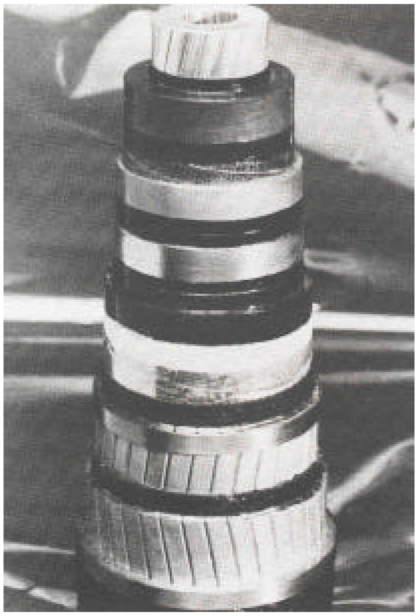

Figure 9. Pirelli Cable Design No. 116 (Bonnet, 1990).

The individual tests were:

1. Baseline electrical test,
2. High stress tensile test,
3. Static flexual rigidity test,
4. Dynamic flexual rigidity and damping coefficient,
5. Crushing test,
6. Repeated flexure test, and
7. Internal pressure test.

The sequence tests were:

1. Crushing test,
2. Bending test,
3. Cable oscillation test under simulated tidal current, and
4. Final electrical test.

The conclusions of the individual tests and the sequence tests were that the cable met the required guidelines for a 300 kV DC submarine cable. Additional tests that reflected the special conditions of the program were conducted and all tests were passed. The electrical strength of the cable and joints exceeded the acceptance requirements for use in the program. After the 30 year simulation there was no evidence of degraded performance of the cable.

A major challenge to laying the proposed underwater power cable is the formidable Alenuihaha channel between Hawaii and Maui. The Alenuihaha is renowned for its difficult currents, harsh wave conditions and strong wind velocities and is the deepest channel in the Hawaiian Islands.

A major component of the HDWC program was the at-sea test, where a test cable with similar characteristics to the proposed power cable was laid multiple times. The most difficult portions of the cable route were chosen for cable laying tests to prove the technical feasibility. The primary objects of the at-sea tests were:

- To verify the ability to accurately lay a power cable within the required path, and
- To verify the ability to control the cable tension on the ocean bottom.

A second objective was to monitor and record the performance of the laying control system, environmental conditions and the associated ship motions and dynamic tension loads in the cable for post-cruise analysis.

An 8,000-m surrogate steel cable was selected to be hydrodynamically similar to the power cable. This cable was laid and retrieved a total of three times. The first lay, under Integrated Control System control, established the success of horizontal placement accuracy with the cable being placed within 3 meters of the objective. The second and third lays were up and down the steep Kohala slope which is in the Alenuihaha channel.

The cable, while shown to be technically feasible through the research project, did not prove to be economical. Cost proposals for commercial installation of the cable demonstrated that the project could not be supported without significant government subsidies, which were not possible at the time. Currently, the state's policy supports geothermal energy production on the Big Island exclusively for use on that Island.

PUNA GEOTHERMAL VENTURE POWER PLANT (PUNA GEOTHERMAL VENTURE, 2002a)

In 1990, The Puna Geothermal Venture Facility, situated on 25 acres of a 500-acre plot, located 21 miles south of Hilo on the Big Island, replaced the HPG-A facility. This facility is in the geologic region known as the Lower East Rift Zone. Puna Geothermal Venture is the first commercial geothermal power plant in the state of Hawaii and currently is capable of producing about 30 MW of power. The power plant comprises 10 combined cycle ORMAT Energy Convertors (OECs) installed in parallel. Each OEC consists of a Level I topping steam turbine and a Level II organic turbine connected to a common generator (Ormat, undated) (Figure 10 and 11).

Puna Geothermal Venture provides nearly a quarter of the power consumed on the Island of Hawaii. That is enough electricity to meet the needs of more than 25,000 residents and visitors. As of April 2002, the power plant has produced a total of 1.9 billion kWh, and displaced a total of 552 tonnes of oil (Puna Geothermal Venture, 2002b).

In 2000, Puna Geothermal Venture announced its intention of doubling its electrical generation capacity from 30 MW to 60 MW. The expansion would be over an unspecified period of time. The wells supply geothermal steam at high pressure which must be reduced with valves before the steam goes through the generators. Puna Geothermal Venture plans to place an 8 MW generator at the well to reduce pressure to

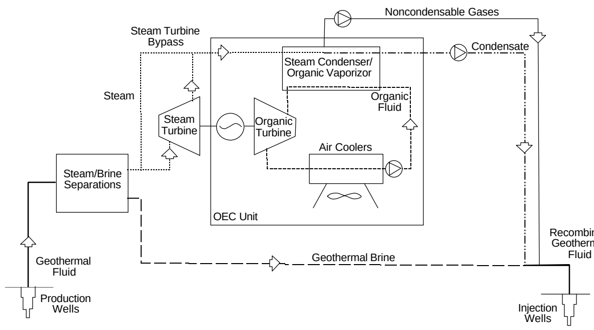

Figure 10. Schematic of the Puna Geothermal Venture Facility (Puna Geothermal Venture, 2002).

Figure 11. Puna Geothermal Venture Power Plant (Ormat, undated).

the other generators while producing power. In the long run, the company can increase capacity to 50 MW without any new wells (Thompson, 2000).

In 2001, Puna Geothermal Venture was chosen to operate the Puna Geothermal Research Center (Noi‘i O Puna) facility by the Natural Energy Laboratory of Hawaii Authority (Pacific Business News, 2001). The Puna Geothermal Venture proposal consisted of continuing the existing activities and to develop new operations without doing any further drilling. They plan to solicit proposals from entrepreneurs and sell them thermal energy. PGV will refurbish and expand the visitor center and will also make reasonable efforts to solicit proposals from the public for the development, construction, operation and maintenance of a geothermal heat source on the property. If PGV receives a bona-fide proposal, they will make available, for reasonable compensation, facilities to transfer surplus heat from their neighboring geothermal facility and area within the Noi‘i O Puna facility for geothermal related businesses of local entrepreneurs (Hawaii eBuzz, 2002).

BARRIERS THAT HAVE BEEN ENCOUNTERED (Lesperance, 1990 and 1991; Environment Hawaii, Inc. 1992; Energy Resources and Technology Division, 2002d)

A number of potential barriers to geothermal development in Hawaii have been overcome but some remain. A couple of the barriers, regulations and public acceptance, are discussed below.

Regulations

The regulatory regime seems to be quite complex. There is the Geothermal Resource Subzone (GRS) Assessment and Designation Law (Act 296, SLH 1983), the Hawaii County Planning Commission's Rule 12, and Act 301, SLH 1988 just to name a few.

The Geothermal Resource Subzone Law stated that the exploration and development of Hawaii's geothermal resources are of statewide benefit and this interest must be balanced with preserving Hawaii's unique social and natural environment.

Three Geothermal Resource Subzones were designated by the Board of Land and Natural Resources after evaluating a number of factors including social and environmental impacts. The subzones total 22,300 acres in the middle and lower Kilauea Rift Zone and 4,000 acres in the Haleakala Southwest Rift Zone.

Public Acceptance

The development of geothermal energy in the Kilauea East Rift Zone has stirred a significant amount of controversy. The experimental HGP-A power plant was not perceived as a "good neighbor" due to emission releases, the extent of brine ponds beyond the plant boundaries, and an unkempt appearance of the plant itself because of limited maintenance. Further exploration was opposed, often vehemently, by people expressing concern over various issues, including impacts on Hawaiian cultural and religious values, potential geologic hazards, public health, and loss of native rainforest, as well as changing the rural nature of Puna. During the establishment of the Puna Geothermal Venture plant, an episode of planned open venting and a number of uncontrolled steam releases stimulated the evacuation of some nearby residents and enhanced fears that the resource could not be safely tapped.

Since the PGV plant has been operating for a decade, most Hawaii residents have accepted it as part of the power supply. However, there is continued concern about health and environmental issues among some residents near the plant which have resulted in investigations by the US Environmental Protection Agency and a program documenting residents' health problems which they attribute to geothermal emissions. The relationship between PGV and its neighbors appears to have improved with better communication between the company and the adjacent residents.

Among the issues which have concerned geothermal opponents are:

- Interference with worship of the Goddess Pele.
- Interference with certain Native Hawaiian practices

Rainforest destruction
- Possible health and safety impacts
- Disruption of the way of life for nearby residents
- Hydrogen sulfide and other air quality issues
- Noise
- Increased strain on an inadequate infrastructure
- Impact on native fauna and flora.

In more detail some of these issues are described below.

According to state regulations, the exploration and development of geothermal resources can be permitted within conservation, agricultural, rural, and urban areas. The vast majority of resources are located in predominantly rural areas and in some cases, geothermal resources may be present in more primitive tracts where direct human impacts or occupation are minimal such as the Wao Kele O Puna rainforest. In the former case, many of the residents of these rural areas moved there to escape urbanization and industrialization of more populous countries of states (e.g., Honolulu, California), and the implementation of an industrial activity–the generation of geothermal power–was completely contrary to their lifestyle. In the latter situation, the installation of power production facilities in the rainforest–even one degraded by invasive exotic/non-native plants and animals–was equally offensive to other interest groups in the state.

An uncontrolled venting incident in June 1991 at the Puna Geothermal Venture project on the Big Island released hydrogen sulfide and other gases, and gave ample validation to the concerns of the area residents regarding the adverse impacts of this development on their communities. As a result of the "blowout," a Geothermal Management Plan was developed that has enabled state and county agencies to better regulate geothermal activity and enforce permit conditions. Nonetheless, geothermal wells are sometimes vented intentionally for a few hours to clear the well and pipelines resulting in a temporary release of steam and abated gases. These events can be noisy for a short time and, in addition, the power plant equipment (e.g., cooling tower fans, pumps, etc.) do emit continuous low-level noise during normal power plant operations. Hence, some impact on the community from power production is inescapable, and serves as a continuous irritation to those who feel that their environment has been invaded by industrialization.

A more intangible objection was also raised by some native Hawaiians who claimed that the development of geothermal power was interfering with their worship of Pele, the Goddess of volcanoes. These objections were taken as far as the U.S. Supreme Court, who found that geothermal development does not interfere with religious freedom.

The disputes over the development of a geothermal industry in Hawaii culminated in several actions by the state and the geothermal opponents that effectively ended any serious effort to develop any significant geothermal production capacity on the island of Hawaii, or in the state at all. In 1991, there were two entities actively pursuing development of the geothermal resource on the Kilauea East Rift Zone: Puna Geothermal Venture on the lower rift, and True Geothermal Energy Company in the middle rift area. The former was in the process of constructing their power plant and proving up their resource; whereas, the latter, having spent about 10 years struggling with the regulatory environment, was in the process of drilling the first of their exploration wells. When Puna Geothermal Venture lost control of one of their wells during drilling and allowed the uncontrolled release of steam from their exploration well, the state regulatory agencies suspended–indefinitely–the geothermal drilling permits of both Puna Geothermal Venture as well as the True Geothermal Energy Company. The latter company interpreted the loss of their permits–even though they were in compliance with their permit conditions–as an indication of waning political support for geothermal development by the state political powers. This loss of support, as well as less than hoped-for success in their exploratory drilling, ultimately led to their abandonment of further efforts to develop their project on the middle rift subzone.

The second event that further eroded momentum for the geothermal program resulted from an effort by the state to obtain additional federal support for the combined geothermal/inter-island cable program. In this effort, the state presented all of the state- and federally-sponsored research, development, and demonstration activities up to that date as a single unified program designed to lay the foundation for large-scale, 500-MWe-development of Hawaii's geothermal resources. Although this strategy was intended to rationalize significant, additional federal investment in the RD&D effort, it had unexpected and adverse consequences. Soon after the state presented the program as a unified effort, the Sierra Club Legal Defense Fund brought suit against the state and the U.S. Department of Energy in an effort to force the relevant agencies to conduct a Federal Environmental Impact Statement on the full 500-MWe development. The U.S. DOE expended -$5 million in an effort to conduct an EIS, but made minimal progress in meeting the demands of the geothermal opponents. Ultimately, the state and DOE settled with the plaintiffs in the suit by signing a "consent decree" that effectively barred the Hawaii governor–for the duration of his term in office–from providing support to any program that would further the state's objective of developing large-scale geothermal power production or transmission inter-island. The state's capitulation to the demands of the opponents, as well as a declining real cost of petroleum for electrical power production, effectively ended any serious effort to develop geothermal power generation beyond that of the Puna Geothermal Venture efforts on the lower east rift zone.

Nearly a decade has passed since many of these events occurred. Puna Geothermal Venture was, however, able to bring a 35-MWe power plant online–after many delays and much greater costs than had been anticipated by their original investors. Although technical challenges remain a significant concern in the operation of this facility, it has managed to produce power with a minimum of steam releases into the community and a minimum of public controversy. And the company has been able to obtain permits to expand their production to 60 MWe. However, there are no current plans to expand their production capacity, and there is little serious discussion given to significant expansion of geothermal capacity either on the island of Hawaii or elsewhere in the state. Undoubtedly, this situation is the result of the currently low cost of petroleum–in "real" dollars–but is also in recognition of the severe regulatory and political risks any new investment in significant geothermal production capacity would face in Hawaii today.

RENEWABLE PORTFOLIO STANDARD (Energy Resources and Technology Division, 2002a, 2002b and 2002c)

A Renewable Portfolio Standard (RPS) is a policy to encourage the use of renewable energy sources. It sets minimum targets for the production of electricity generated from renewable resources. The aim is to ensure deployment of renewable energy to enjoy the benefits of reduced energy costs, reduced exposure to the economic effects of volatile oil markets, risk management by diversifying generation options, job creation and economic benefits, and environmental benefits.

For a state such as Hawaii, with its extremely high dependence on imported fuels for energy (90% of the energy supplies - oil and coal - are imported), increased use of renewable energy would achieve increased energy security, reduce some of the environmental risks associated with fuel transport, and reduce the flow of money out of the state. The cost of electricity in Hawaii is the highest of any state in the United States with average price per kWh in September 2000 of $0.144 -- over twice the U.S. average price per kWh of $0.0691.

Not only were Hawaii's electricity prices per kWh the highest in the nation in October 2000, electricity revenues per kWh for Hawaii utilities grew much faster than the U.S. average over the years since 1990. Hawaii's revenues per kWh were 59.6% higher than the average for 1990 while the U.S. average was only 3.3% higher. For comparison, Honolulu consumer prices increased about 25.5% from 1990 to 1999.

Electric utilities in Hawaii are "regulated monopolies" meaning they are allowed to operate without competition, but must follow rules set by the Public Utilities Commission. By adopting a renewable portfolio standard, the use of renewable energy becomes one of those rules.

Hawaii's dependence on fossil fuels is expected to grow over the coming decade unless action is taken to increase the use of renewable energy. In 1999, Hawaii's four electric utilities sold 9,373.8 Gigawatt hours (GWh) of electricity. Statewide, utilities forecast that electricity sales will grow at an average annual rate of 1.6% during the 1999 through 2010 period, reaching approximately 11,192 GWh in 2010.

In 1999, renewable energy (geothermal, municipal solid waste, bagasse, landfill methane gas, hydro and wind) was used to produce 7.2% of the electricity generated for sale by the four electric utilities. Renewable energy generation capacity was reduced in 2000 by the closure of Lihue Plantation on Kauai and Pioneer and Paia Mills on Maui. If the remaining renewable energy resources in operation at the end of 2000 continue in operation through 2010, they will provide an estimated 642 GWh of sales during each year of the period. This will amount to approximately 6.6% of total electricity sales in 2001. As electricity demand grows, the percentage of electricity sales from renewable resources will decline to approximately 5.7% statewide by 2010.

Table 1 shows the generation in Hawaii used to produce electricity for sale to utility customers in Hawaii as of the end of 2000.

Hawaii has an abundance of renewable energy resources. Several studies have shown that at least 10.5% of Hawaii's electricity could be generated from renewable resources by 2010 with no increase in cost to Hawaii's residents.

Increased use of renewable energy sources through the implementation of a RPS can result in many benefits to Hawaii including:

- Reduced cost of fuel for electricity generation
- Reduced reliance on imported oil supplies and exposure to the volatile prices of the world oil market

Table 1. Electricity Generation for Utility Sales (End of 2000) (Energy, Resources and Technology Division, 2002a).

HECO	HELCO	KE	MECO
1161.0 MW OFS	65.0 MW OFS	10.0 MW OFS	32.4 MW OFS
129.0 MW CT	45.3 MW CT	42.9 MW CT	102.4 MW CT/DTCC
180.0 MW AFBC	42.0 MW IC Diesel	44.0 MW IC Diesel	114.9 MW IC Diesel
180.0 MW LSFD DTCC	22.0 MW Coal Steam		
	62.0 MW DTCC		
46.0 MW MSW	30.0 MW Geothermal	8.7 MW Hydro	12.0 MW Bagasse/Oil/Coal/Steam
3.2 LF Gas	15.7 Hydro	4.0 MW Bagasse	5.9 MW Hydro
	9.1 Wind		

OFS - Oil-fired Steam; CT - Combustion Turbine; AFBC - Atmospheric Fluidized Bed Coal;
LSFO - Low-sulfer Fuel Oil; DTCC - Dual-train Combined Cycle; MSW - Municipal Solid Waste
LF Gas - Landfill Methane Gas; IC Diesel - Internal Combustion Diesel

- Risk management by diversifying the portfolio of electricity generation options
- Job creation and economic benefits
- Environmental benefits.

CONCLUSIONS

There is still resistance to using geothermal energy by some members of he local population even though the above issues have been and will continue to be addressed by the government and the developers. However there are well organized groups such as the Pele Defense Fund, Rain Forest Action Network and various community organizations that will continue to express concern in various ways about the ability of the government and developers to provide socially and environmentally sound geothermal power. Further, the level of support given by the state's political establishment to expansion of geothermal capacity–there is presently only funding for one geothermal staff person at the state level–remains vanishingly small.

REFERENCES

Bonnet, W., 1990. "Hawaii Deep Water Cable Program," *Geothermal Resources Transactions*, Vo. 14, Part I, August 1990, p. 755-762.

Energy, Resources and Technology Division, 2002a. "Renewable Energy Requirements," http://www.state.hi.us/dbedt/ert/rps.html, Energy, Resources and Technology Division, Department of Business, Economics and Tourism, State of Hawaii, Downloaded 4/9/2002.

Energy, Resources and Technology Division, 2002b. "Renewable Portfolio Standards Report," http://www.state.hi.us/debt/ert/rps00.html, Energy, Resources and Technology Division, Department of Business, Economics and Tourism, State of Hawaii, Original report prepared by GDS Associates, Inc., Downloaded 6/24/02.

Energy, Resources and Technology Division, 2002c. "Renewable Energy," http://www.state.hi.us/dbedt/ert/renewable.html, Energy, Resources and Technology Division, Department of Business, Economics and Tourism, State of Hawaii, Downloaded 6/12/2002.

Energy, Resources and Technology Division, 2002d. "Geothermal Fact Sheet," http://www.hawaii.gov/dbedt/ert/geo-hi.html, Energy, Resources and Technology Division, Department of Business, Economics and Tourism, State of Hawaii, Downloaded 1/28/02.

Environment Hawai'i, 1992. "At Puna Geothermal Venture, Success is Always Just Around the Corner," *Environment Hawai'i*, Vol. 3, No. 6, December 1992, Environmental Hawai'i, Inc., http://planet-hawaii.com/environment/1292cov.htm, Downloaded 6/18/02.

Fesmire, V. and J. Richardson, Jr., 1990. "The Hawaii Geothermal/Interisland Transmission Project - A Status Report", Geothermal Resources Council Transactions, Vol. 14, Part I, August 1990, p. 763-767.

Gill-Beck, A., 1988. "Direct Heat Uses in Hawaii: The Community Geothermal Technology Program," *Geo-Heat Center Quarterly Bulletin*, Vol. 11, No. 2, Fall 1988, p. 8-12.

Gill-Beck, A., 1990. "Direct Use in Hawai'i: Perspectives and Prospects," *Geothermal Resources Council Transactions*, Vol. 14, Part I, August 1990, p. 751-754.

Hawaii eBuzz, 2002. "NELHA Accepts Proposal for Operation of the Noi'i O Puna Geothermal Research Facility," *Hawaii Ventures* - January eBUZZ News, http://www.hawaiiventures.com/news0102-1.htm, Downloaded 6/21/02.

Lesperance, G., 1990. "Issues Related to Geothermal Development," *Geothermal Resources Council Transactions*, Vol. 14, Part I, August 1990, p. 783-785.

Lesperance, G., 1991. "Public Information in Hawaii," *Geothermal Resources Council Transactions*, Vol. 15, October 1991, p. 437-442.

Ormat, Undated. Puna Geothermal Power Plant, Flyer, Ormat, Inc., Sparks Nevada.

Pacific Business News, 2001. "Puna Geothermal Wins NELHA Contract," American City Business Journals Inc., December 27, 2001. Downloaded 1/28/02

Puna Geothermal Venture, 2002a. "Puna Geothermal Venture," http://www.punageothermalventure.com/, Puna Geothermal Venture, Downloaded 6/26/02.

Puna Geothermal Venture, 2002b. "Current Facts," http://www.punageothermalventure.com/facts.htm, Puna Geothermal Venture, Downloaded 6/26/02.

Thomas, D. T., 1984. "Geothermal Resources Assessment in Hawaii, Final Report," Hawaii Institute of Geophysics, Honolulu (Technical Information Center DOE/SF/10819-TI), 114 p.

Thomas, D. T., 1985. "Characteristics of the Geothermal Resource Associated with the Volcanic Systems in Hawaii," *Geothermal Resources Transactions*, Vol. 9 – Part II, August 1985, p. 417-422.

Thomas, D. T., 1987. "A Geochemical Model of the Kilauea East Rift Zone," *U.S. Geological Survey Prof. Paper 1350*, *Volcanism in Hawaii*, Vol. 2, Chap. 56, p. 1507-1525.

Thompson, 2000. "Puna Plant to Double Geothermal Capacity," *Honolulu Star - Bulletin Hawaii News*, http://starbulletin.com/2000/07/07/news/story13.htm, Downloaded 6/21/02.

THERMAL SPAS: AN ECONOMICAL DEVELOPMENT ALTERNATIVE ALONG BOTH SIDES OF THE URUGUAY RIVER

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INTRODUCTION

The origin of balneology in the region is associated with oil exploration efforts that began about 60 years ago. Deep wells, like the ones at Gaspar, Belén, Arapey, Artigas, Daymán, Guaviyú, Almirón, Paso Ulliestie (Figure 1) were drilled in the Uruguayan sector of the Chaco-Paraná Basin. Some of them brought about the development of thermal spas ("Centros Termales" in Spanish) that are still in operation.

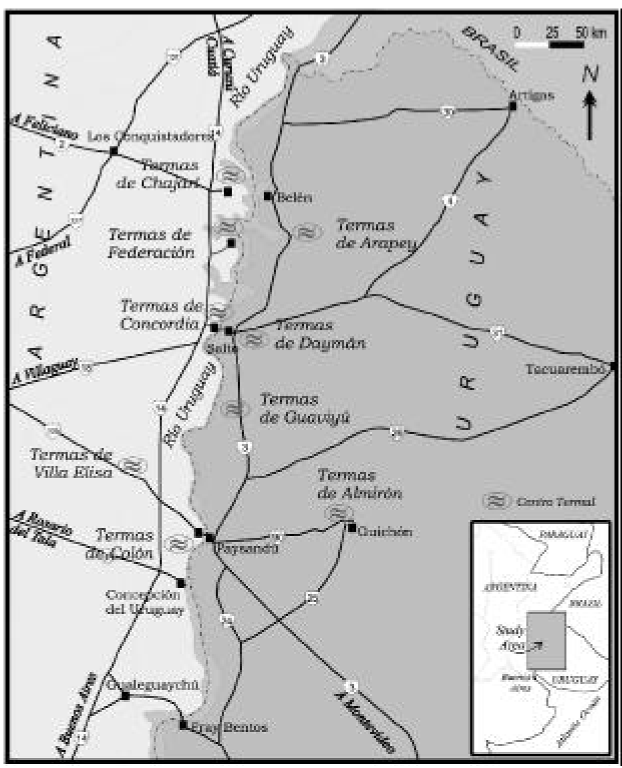

Figure 1. ***Location of the study area and of thermal spas in northeastern Argentina and western Uruguay.***

In the 1960s and 1970s, mainly based on geologic data from the Uruguayan wells, the Argentine part of the Basin was studied. Only one deep well was drilled in the general area, at Nogoyá about 150 km west-northwest of Concepción del Uruguay (Figure 1). It was plugged and abandoned since no evidence of hydrocarbons was found. Recent studies by SEGEMAR (Pesce, et al., 2001) suggest the existence of thermal waters at Nogoyá similar to the ones being produced at Villa Elisa.

These low-temperature geothermal resources are found in a vast volcanic-sedimentary basin hosted in an inter-cratonic region of low-to-normal thermal gradient. Three thermal aquifers with large potential for direct geothermal applications have been identified and characterized (Pesce, 2001). The governments of both countries have recognized the importance of these hot waters and are promoting the development of the spas and tourist centers around the wells tapping them.

The wells supplying thermal water to the spas produce from different levels of the Guaraní Aquifer System (GAS), depending on location (Table 1). The lower aquifer exploited at Almirón in Uruguay and at Villa Elisa in Argentina, is quite saline; it is in Lower Carboniferous-Middle Permian glaciomarine deposits. The middle and most impor-tant thermal aquifer, is in Lower Triassic to Lower Jurassic sedimentary rocks (eolian at the top, fluvial, deltaic and lacust-rian toward the bottom). Generally, this highly productive aquifer is of low salinity, however as it deepens towards the east-southeast its salinity increases. The spas at Chajarí, Federación, Concordia, Arapey, Dayma and Guaviyú tap into this aquifer. The upper aquifer is in Lower Jurassic to Upper Cretacic sedimentary rocks that are interlayered with thick basaltic flows, particularly toward the bottom. The spa at Colón extracts water from this low salinity water-bearing unit.

THE GUARANÍ AQUIFER SYSTEM OF ARGENTINA AND URUGUAY

The GAS has three levels of thermal aquifers that correspond to separate hydrogeologic systems.

Lower GAS Level. Montaño and Collazo (1998) described the lower level of the GAS in Uruguay where it is found in glacial and fluvioglacial units corresponding to the Lower Permian San Gregorio Formation which correlates to the Sachajoy and Charata Formations of Argentina (Figure 2). The sedimentary rocks, consisting of fine to medium sandstones and conglomerates of the Tres Islas Formation (similar to the Chacabuco Formation of Argentina), were

Table 1. Guaraní Aquifer System. Thermal Well Data.

Well	Latitude (S)			Longitude (W)			Approx. Elev. (m.a.s.l.)	Top Serra Geral Fm. (r.n.m.)	Top Rivera - Tacuarembó Fms. (r.n.m.)	Top Carbonif.-Permian Fms. (r.n.m.)	Top of Basement (m.a.s.l.)	Total Depth (m.b.b.p.)	Temp. (º C)	Flow Rate (L/min)
	Deg.	Min.	Sec.	Deg.	Min.	Sec.								
Colón	32	12	31	58	8	50	25	-209	-	-	-765	1500	33	2250
Arapey	30	57	36	57	31	48	60	60	-477	-	-	?	41	5800
Chajarí	30	44	46	58	0	46	55	-57	-611	-	-	811	38	6100
Federación	30	58	32	57	55	41	35	-7	-776	-	-	1301	41	7500
Concordia	31	17	41	58	0	16	48	-20	-935	-	-	1175	43	4400
Daymán	31	32	24	57	53	24	20	20	-935	-2000	-2155	2206	45	5166
Guaviyú	31	51	36	57	53	24	33	33	-642	-	-	958	38	6800
Paso Ullestie	32	27	0	57	58	48	25	-235	-	-875	-950	?	-	-
Almirón	32	39	36	57	11	24	68	10	-	-568	-860	?	34	312
Villa Elisa	32	7	40	58	27	18	50	-309	-	-898	-	1032	41	216

deposited in continental to littoral environments. In Argentina, in the western part of the basin, the lower level is represented by the Chacabuco, Charata and Sachajoy Formations. At the bottom of this level there are sedimentary rocks deposited during a marine transgression. The top corresponds to an Early Permian regression period (Chacabuco and Charata Formations). The Chacabuco Formation (Padula, 1972), and Charata and Sachayoj Formations (Padula and Mingramm, 1969) present hard, micaceous, gray-to-dark-gray clays and sometimes bituminous shales, as well as gray limestone and medium-to-fine sandstone interlayers. The Charata Formation, representing Upper Carboniferous glacial and fluvioglacial environments, is formed by silty, gray clays; tillite intercalations are abundant near the base of the formation.

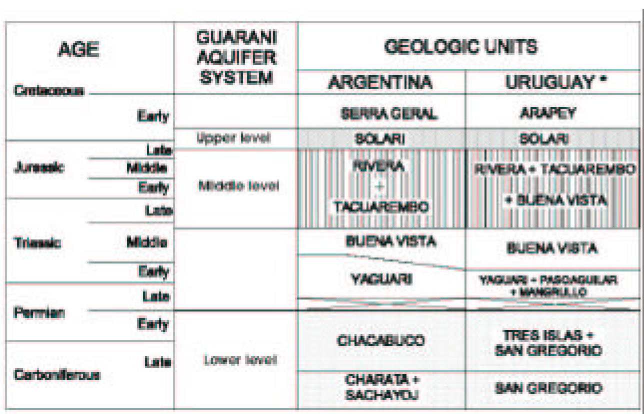

Figure 2. Stratigraphy of the Guaraní Aquifer System.

The thickness of the lower GAS level varies between 292 m in the southeastern part of the basin (i.e., in the Almidón well; Figure 3) and 95 m toward the south (i.e., in the Paso Ullestie well). Near the Uruguay River this level was not deposited because of a basement high in that region. It is not encountered in the wells at Colón and Concepción del Uruguay, but it is found to the west in the Villa Elisa well.

Middle GAS Level. Because of its productivity, the middle level is the most important one in the GAS. Montaño and Collazo (1998) mention that the aquifer outcrops in some areas. It is found in the Rivera and Tacuarembó Formations (Falconer, 1931; Ferrando and Andreis, 1986) which form the largest known eolian deposit that may extend over a 1.5 million square kilometer area (Sprechmann et al., 1981). The outcrops, restricted to Uruguay, occur along a north-south band that starts east of the city of Rivera, and ends at the Negro River to the south, passing through the city of Tacuarembó. These large outcrops are the main recharge areas of the middle GAS which is exploited on both sides of the Uruguay River.

The wells drilled at Arapey, Belén, Federación, Charají and Concordia show that the Rivera and Tacuarembó Formations extend toward the west into Argentina (Pesce, 2001). The southern limit of the middle level is north of the Almirón, Colón and Villa Elisa wells. The total thickness of this level could only be determined in the Belén well (i.e., 526 m) that had been drilled looking for oil. All the other wells which were exploring for thermal waters only penetrated the upper few meters of the two units.

The lithologic and sedimentary characteristic of the Early-to-Lower Jurassic Rivera Formation (e.g., sandy dunes, eolian and ephemeral torrential fluvial deposits) indicate that it was deposited in a desert environment. It is composed mainly by fine-to-medium, well-sorted, cross-bedded quartzitic sandstones of eolian origin. Drill cuttings from the Chajarí wells show that they have no or little cement, and a porosity of about 30%.

The sedimentary rocks of the Middle Triassic-to-Early Jurassic Tacuarembó Formation are mainly of fluvial type (i.e., river bed, alluvial plain, and overflow deposits). It is composed by very fine-to-medium grained, well-to-regularly sorted, feldspar, quartz and micaceous (mainly muscovite) sandstones with clay cement, and by green, redish siltstones and mudstones, friable muscovite shales, and intraformational conglomerates.

Upper GAS Level. The upper aquifer of the GAS is hosted in continental sandstones of the Solari Formation (Herbst, 1971) interstratified with the lower basalts of the Serra Geral Formation (White, 1908). At present, this thermal aquifer is only being penetrated by the Colón well, west of the Uruguay River, at 795 m below sea level (Figure 3). In this part of the basin the basement presents a structural high, the Colón- Concepción del Uruguay Horst, that did not allow the deposition of the formations corresponding to the lower and medium GAS levels. Fine and medium grained quartz sandstones and some coarse psammitic interlayers predominate the lithology of the upper GAS level. Some basalt flows are also found. There is evidence of alternating

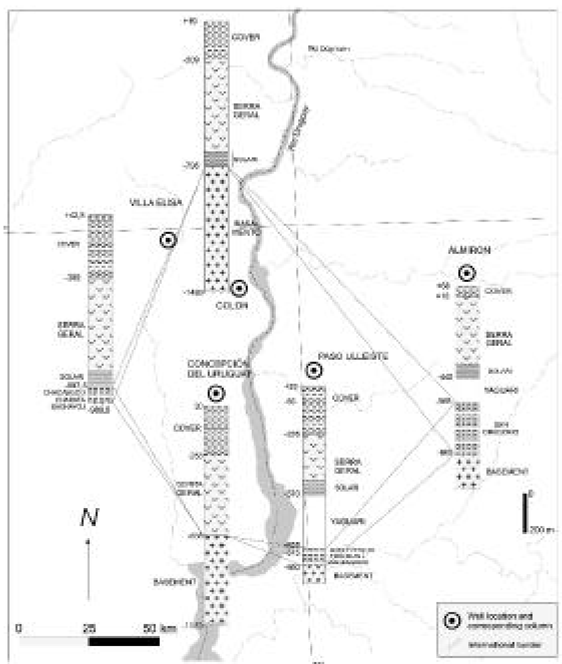

Figure 3. ***Lower level of the Guaraní Aquifer System. Correlation between wells in the southern part of the study area.***

basaltic effusions, and erosion and deposition events occurring under arid conditions. Sediments are predominantly eolian, with smaller amounts of deposits.

The north-south profile along the Uruguay River (Figure 4) was prepared using the information from the Chajarí, Federación, Concordia, Colón, Concepción del Uruguay and Gualeguaychú wells. The Colón-Concepción del Uruguay Horst that had an important effect on sedimentation, is clearly discernable. Its highest part (at 686 m below sea level) was encountered by the Concepción del Uruguay well. Toward the north and south where the basin becomes deeper, the lower and medium GAS levels are found in the wells. The lower level occurs south of the horst (i.e., at Gualeguaychú).

In the southern and central parts of the area under study the upper and medium levels of the GAS produce the thermal fluids. The western and eastern edges of the horst and the southern limits of the medium and lower levels have been established by correlating the Almirón, Colón, Paso Ullestie, Concepción del Uruguayand Villa Elisa wells (Figure 3).

HYDROLOGY

The GAS is confined over 90% of its area. In the remaining 10%, where the aquifer is unconfined, most of the recharge occurs (Campos, 2000). The chemical characteristics of the GAS waters are given in Table 2.

Montaño and Collazo (1998) mentioned that the waters in the Rivera and Tacuarembó Formations are potable everywhere. The waters are of calcium chloride and calcium bicarbonate type. The concentration of calcium is higher than that of sodium which could be related to the poor cementation of the Tacuarembó Formation that some times is calcareous (Montaño and Collazo, 1998). The mean total hardness, expressed as $CaCO_3$, is 45 mg/L; the average dry residue is 120 mg/L.

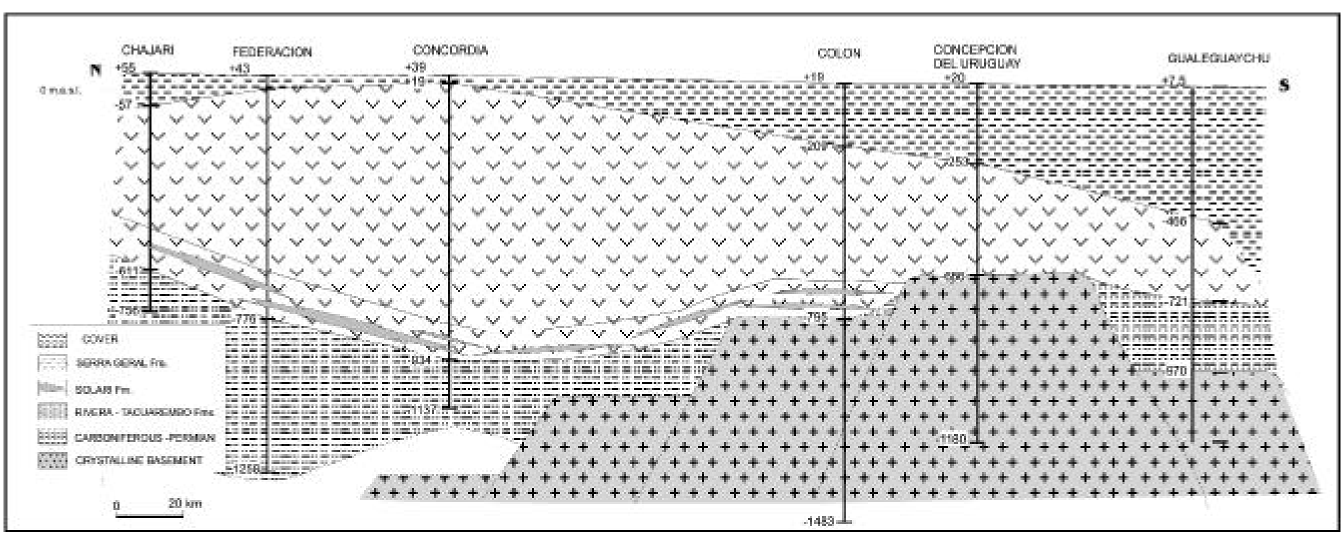

Figure 4. ***North-south geologic section along the Uruguay River showing the Colón-Concepción de Uruguay Horst. Elevation given in meters.***

Table 2. Chemical Analysis of Waters From the Three Levels of the Guaraní Aquifer System.

Geothermal Area	pH	EC [µS/cm]	TDS [mg/L]	Na+ [mg/L]	Ca++ [mg/L]	Mg++ [mg/L]	Cl- [mg/L]	SO4= [mg/L]	HCO3- [mg/L]	CO3= [mg/L]	SiO2 [mg/L]	K+ [mg/L]	Fe++ [mg/L]	F- [mg/L]	B [mg/L]	NO3- [mg/L]	Li+ [mg/L]	Al+++ [mg/L]	Mn++ [mg/L]	As+++ [mg/L]	Water Type
U P P E R L E V E L																					
Colón	8.5	1180	620	235	1.4	0.5	105	74	318	12	22	0.7	0	3.1	1.4	n.d.	0.03	<1	0	0.01	Sodium Bicarbonate-Sodium Chloride
M I D D L E L E V E L																					
Arapey *	8.2	416	297	98	19	10	33	20	175	49		6.3	0	0.2		0.1			0		Sodium Bicarbonate
Chajarí	8.2	918	569	175	11	5	120	40	238 *	< 5	----	6	0.01	0.6	0.17	n.d.	< 0.1	0.017	< 0.005	0.021	Sodium Bicarbonate-Sodium Chloride
Federación	8.5	1250	698	240	16	5.8	199	92	236	2.6	7.9	4.3	0.2	0.5	0.23	4	0.04	0	< 0.05	0.03	Sodium Bicarbonate-Sodium Chloride
Concordia	8.5	554	326	118	4.6	1.8	21	8.4	290	3.8	9.6	2.5	< 0.2	0.7	0.17	3.1	0	0	0	0.06	Sodium Bicarbonate
Daymán *	7.8	806	455	140	7	2	32	28	295.24	0		2	0	0		0			0		Sodium Bicarbonate
Guaviyú *	8.7	997	712	245	1.8	0.4	80.97	70	302	88		2	0	1		0.1			0		Sodium Bicarbonate
L O W E R L E V E L																					
Paso Ullestie *		3000	2803	900	41.5	5.8	911.68	602	129.32	0		10	0	0		0			0		Sodium Chloride
Almirón*	7.2	8000	8044	2000	233	2.9	2933.95	1215	37	0		15.01	0	0		0			2.9		Sodium Chloride
Villa Elisa	7.7	18900	14500	4900	191	70	5070	4800	98	0	15	13	0.4	1.1	4.1	n.d.	0.47	<1	<0.05	0	Sodium Sulfate-Sodium Chloride

The GAS presents three confined aquifer levels. The top of the system corresponds to the upper and mid-parts of the Serra Geral Formation; in some areas and because it presents fractures, the formation behaves as an aquitard (Araujo et al., 1999).

As indicated earlier, the GAS deepens toward the east-southeast where it presents a remarkable number of reactivated regional faults (Aráujo et al., 1995) that permits the infiltration of waters from overlying units. Since in the western part of the basin these units are Tertiary marine formations, there is an increase in total dissolved solids toward the west (Pesce, 2001).

The lower level of the GAS is exploited in the extreme southern part of the basin where three wells have been drilled (i.e., at Almirón, Paso Ullestie and Villa Elisa). The Almirón well reaches the San Gregorio Formation at less that 568 m depth; at Paso Ullestie, at less than 855 m; and at Villa Elisa (Argentina), the Chacabuco Formation is found at less than 897 m depth, indicating that the lower GAS level deepens toward the west. The waters are of sodium sulfate-chloride type. The amount of total dissolved solids (TDS) increases toward the west (i.e., the average TDS is 5423 mg/L in the east and 14,500 mg/L in the west. The amount of magnesium in the waters also increases in that direction. The average pH of the waters is 7.5. The electrical conductivity varies between an average of 5500 FS/cm in Uruguay to 18,900 FS/cm in Argentina.

The middle level is being produced in the south-central part of the region under study, where the Rivera-Tacuarembó can be found (i.e., in the Guaviyú, Daymán, Concordia, Arapey, Federación and Chajarí wells). The major ions in the thermal waters of this level are mainly of sodium bicarbonate type. The wells in Federación and Chajarí produce high chloride content waters. This can be explained by the hydrogeologic model for this aquifer that shows the groundwaters moving from east to west.

The temperatures in the middle level vary between 38º and 46ºC; the pH (i.e., 8.3) is almost constant throughout this level. The average TDS is 509 mg/L; it varies between 455 mg/L (Arapey) and 712 mg/L (Guaviyú).

The waters in the upper GAS level (only produced at Colón) have a temperature of 33ºC, a pH of 8.5 and TDS of 620 mg/L; they are mainly of sodium bicarbonate-chloride type. Sodium and potassium concentrations are higher than that of calcium and magnesium, and the fluor content is high. The waters' electrical conductivity is 1180 FS/cm.

GEOTHERMAL DEVELOPMENT

In the mid-1990s a number of people, witnessing the successful spa industry in Uruguay, proposed similar developments on the Argentine side of the Uruguay River. This led to the drilling of the 1260 m deep Federación well which produced 43ºC waters and the opening of the first thermal spa in northeastern Argentina in January 1997.

After that successful well, others were drilled at Concordia, Colón, Villa Elisa, Concepción del Uruguay and Gualeguaychú. Unfortunately because of lack of appropriate exploration data and bad completion, some did not encountered thermal waters, like the ones at Concepción del Uruguay and Gualeguaychú, and others were drilled too deep (e.g. the 1502-m deep Colón well than penetrated more than 600 m of crystalline basement). Note that all the thermal wells on both sides of the Uruguay River are flowing artesian wells.

The integrated study of the basin and the economic success of the spas is resulting in the rapid development of the region's low-temperature geothermal resources. Five additional wells and associated spas are being planned in Argentina and two new ones in Uruguay. This shows the important role of these developments in the economy of the region.

The growth of economic activity is made obvious by the fast increase in the number of hotel beds in towns having spas. For example, at Federación that number went from 182 in 1994 to 2150 in 2001 (Figure 5). The opening of a spa tends to be reflected by a jump in the number of beds in town.

Statistics collected by the government of the Province of Entre Ríos where for all of the thermal spas located in northeastern Argentina, show a constant growth in the number of tourists visiting the spas; a record number visited during Easter 2002. In the case of Federación the increase of tourist activity is surprisingly high; during the January-June 2002 period more than 210,000 people visited the spa, compared to 150,840 for the twelve months of 2001 (Figure 6). Part of this increase is related to the recent devaluation of the

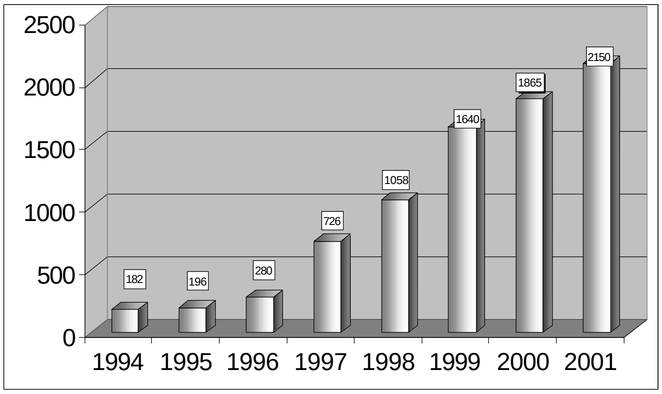

Figure 5. Growth in the number of hotel beds at Federación Thermal Spa.

Argentine peso which lowers the costs for visitors from neighboring countries. It is estimated that only 10% of the visitors are locals, the rest are from other parts of Argentina and from abroad.

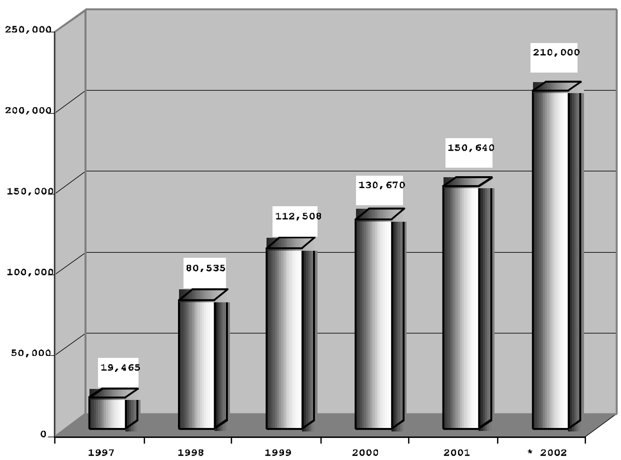

Figure 6. Number of tourist visiting the Federación Thermal Spa.

Figure 7. Colón Spa, Argentina.

The drop in unemployment from 25% to 7% reflects the importance of these centers on the economy of the region over a four-year period. Main characteristics of the thermal spas using waters from the GAS are given in Table 3.

Figure 8. Concordia Spa, Argentina.

Figure 9. Chajari Spa, Argentina.

Figure 10. Federación Spa,, Argentina.

Table 3. Guaraní Aquifer System. Main Characteristics of the Thermal Spas.

Location (City)	Hotel Beds	Name of the Site	Therapeutic Applications	Facilities
Colón	1033	Complejo Termal Colón	Topical applications: neutralize gastric acidity, help stomach secretion and evacuation, stimulate pancreatic and bile secretions, increase carbohydrate tolerance and facilitate insulin action. Baths: to reduce stress and nervous exhaustion	Outside and covered swimming pools, hydromassage, jet baths, water fountains
Concordia	1098	Vertientes de la Concordia	Baths: Arthrosis, rheumatism, arthritis, skin, digestive and respiratory systems, relaxation, esthetics.	Five swimming pools (two are covered), jet baths, massage salon, camping facilities.
Chajarí	544	Complejo Termal Chajarí	Topical applications: digestive system, stimulation of chlorohydric secretion, bile activity, gastric and intestinal motility. Baths: activation of metabolic changes, helps with muscular contraction and hypertonia. Chronic rheumatism, vertebral arthrosis, traumatisms and skin diseases.	Five swimming pools with hydrojets, bungalows, camping facilities.
Federación	2150	Complejo Termal Municipal Federación	Topical applications: digestive and respiratory systems, bile and intestinal motility stimulant. Baths: Chronic rheumatism, vertebral arthosis, locomotive apparatus, skin, relaxation.	Outside and covered swimming pools, immersion bathtubs, hydromassage, ozonizer, showers, steam cabins, masotherapy and kinesiotherapy cabins.
Villa Elisa	1245	Termas de Villa Elisa	Baths: Stimulant of cellular functions, cellular trophysm, metabolic secretions. Improve skin and mucose defenses. Antiflogistic and antiseptic actions. Stimulant of respiratory, digestive, vegetative nervous and female genital systems. Recovery from respiratory chronic affections.	Outside and covered swimming pools, hydromassage, jet baths, showers, masotherapy, kinesiotherapy and phyisiatric cabins
Arapey	450	Termas de Arapey	Topical applications: stomach, diuretic and digestive system sedative related to stress symptoms. Baths: stimulant and disensitizing baths. To treat general rheumatism.	Outside and covered swimming pools. Thermal bath cabins, jets.
Salto	2360	Termas de Daymán	Baths: Treatment of stress, rheumatism, traumas, neuralgic, muscular and skeletal affections.	Saunas, hydrojets, jacuzzis, ozone pools, Scottish and Swedish showers, musculation areas, individual and communal swimming pools, physiotherapy areas, aquatic park.
Paysandú	1632	Termas de Guaviyú	Topical applications: digestive, urologic, pulmonar and cardiovascular systems. Detoxification and physiological dehydration. Renal and vesicular stones and filtration affections. Metabolic regulation, diabetes. Baths: Non-inflammatory rheumatism, arthrosis and spondiarthoris, musculatory affections. Skin allergies and asthma.	Four immersion swimming pools, jets for hydromassages.
Guichón	1034	Termas del Almirón	Baths: Salty waters for therapeutic treatments, rheumatism, psoriasis, chronic excemas, and skin diseases in general. Metabolic problems. Chronic bronchitis, detoxification, analgesic and anti-inflammatory treatments.	Two covered swimming pools, jets systems, three immersion pools, motels, camping facilities.

FINAL REMARKS

The data collected from wells drilled during the development of the low-temperature geothermal resources of northeastern Argentina and western Uruguay has allowed a better understanding of the Guaraní Aquifer System, reducing the risks associated with drilling new wells and developing new spas in the region. The popularity of the thermal centers along both sides of the Uruguay River will lead to a further development of these geothermal resources and the construction of new tourist centers, contributing to the growth of the regional economy.

The rapid expansion and importance of the spa industry led to the creation of business and government associations in Argentina and Uruguay and to a regional integration of activities. Strategies have been developed to inform the general public of the benefits of thermal waters and further popularize balneotherapy. Efforts to integrate development and business plans and guidelines have also been conceived. These include holding technical meetings, tourism fairs, developing Websites (Corredor Turístico del Río Uruguay, Mercotur or Todoturismo), all geared toward linking people, organizations and tourist agents.

REFERENCES

Almeida, F.F.M. de and M.S. Melo, 1981. A Bacia do Paraná e o Vulcanismo Mesozóico. Mapa Geológico de Estado de São Pablo, esc. 1:500.000. IPT. SP, I, pp.12-45.

Araújo L.; Barros França, A. and P. Potter, 1995. Aquífero Gigante do Mercosul no Brasil, Argentina, Paraguai e Uruguay: Mapas Hidrogeológicos das Formações Botucatú, Pirambóia, Rosário do Sul, Buena Vista, Misiones e Tacuarembó. UFPR – PETROBRAS, 16 p, maps, Curitiba, Brazil.

Araújo L.; Barros França, A. and P. Potter, 1999. Hydrogeology of the Mercosul Aquifer System in the Paraná and Chaco-Paraná Basins, South America, and Comparison with the Navajo-Nugget Aquifer System, USA. *Journal of Hydrology*, 7, pp. 317-336.

Campos, H.C.N.S., 2000. Modelación Conceptual y Matemática del Acuífero Guaraní, Cono Sur. Acta Geológica Leopoldensia, UNISINOS Serie Mapas, XXIII (4) 50 p.

Falconer, J., 1931. Terrenos Gondwánicos del Departamento Tacuarembó. Memoria Explicativa, Mapa Geológico. Instituto de Geología del Uruguay. Boletín 15: 1-17. Montevideo, Uruguay.

Ferrando, L. and R. Andreis, 1986. Nueva Estratigrafía en el Gondwana de Uruguay. Actas Primer Congreso Latinoamericano de Hidrocarburos, ARPEL, 1: 295.323, Buenos Aires, Argentina.

Herbst, R., 1971. Esquema Estratigráfico de la Provincia de Corrientes, República Argentina. Asociación Geológica Argentina Revista 26 (2), pp. 221-243, Buenos Aires, Argentina.

Montaño, J. and M. Collazo 1998. Hidrogeoquímica del Sistema Acuífero Guaraní (Uruguay). Actas Segundo Congreso Uruguayo de Geología. Geología Aplicada, pp. 395-400, May, 1998, Montevideo, Uruguay..

Padula, E., 1972. Subsuelo de la Mesopotamia y Regiones Adyacentes. Geología Regional Argentina. Academia Nacional de Ciencias de Córdoba, Primer Simposio de Geología Regional, November 15, 1969, pp.. 213-235, Códoba, Argentina.

Padula, E. and A. Mingramm, 1968. Estratigrafía, Distribución y Cuadro Geotectónico – Sedimentario del "Triásico", in Subsuelo de la Llanura Chaco-Paranense. Actas Terceras Jornadas Geólogicas Argentinas, 1: 291-331, Buenos Aires, Argentina.

Pesce A. H., 2001. The Guaraní Aquifer. A Good Prospect for Geothermal Development in Northeastern Argentina. *Geothermal Resources Council Bulletin* 30(5), pp. 199-203, Davis, CA.

Pesce, A. H.; Rivara, A.; Khachatryan, D. and F. Miranda, 2001. Evaluación del Recurso Geotérmico en la Localidad de Nogoyá. Proyecto de Perforación Termal, Provincia de Entre Rios. SEGEMAR, Unpublished report, 185 p, Buenos Aires, Argentina.

Sprechmann P.; Bossi, J. and J. Da Silva, 1981. Cuencas del Jurásico y Cretácico del Uruguay. In: Volkheimer and Musacchio (Eds.) Cuencas Sedimentarias del Jurásico y Cretácico de América del Sur, pp. 239-270. Comité Sudamericano del Jurásico y Cretácico, 351p., Buenos Aires, Argentina.

White, I. C., 1908. Fossil Flora of the Coa Mesures of Brazil. Relatorio Final da Comissão de Estudos das Minas de Carvão de Pedra do Brasil. Impresa Nacional, pp. 339-472, Rio de Janeiro, Brazil.

GEO-HEAT CENTER QUARTERLY BULLETIN SURVEY

In the June 2002 (Vol. 23, No. 2) issue of the GHC Quarterly Bulletin, we published a one-page questionnaire to be mailed back to the Center. We received 55 responses--thanks. The results are summarized below:

1. Background Information

Employment Sector: Public **26**, Private: **29**
Your Location: U. S. **48**, Other **7**

2. General

How long have you been a subscriber?
<l yr **5**, <5 yrs **5**, >5 yrs **29**

What is your overall rating of the Bulletin?
Excellent **39**, Very Good **13**, Fair **3**, Poor **0**

What is your opinion about the proportion of international articles?
Too Many **23**, Too Few **5**, About Right **27**

Would you like to see more technical articles?
Yes **30**, No. **25**

Would you like to see more general articles?
Yes **43**, No. **12**

Would an electronic format for the Bulletin (elimination of the paper version) be acceptable to you?
Yes **30**, No. **25**

Would a semi-annual rather than quarterly format be acceptable to you?
Yes **30**, No. **25**

3. What topics would you like to see covered in future articles? Circle any you are interested in.

Geothermal Heat Pumps **30**
Geothermal Resources **28**
Aquaculture **26**
Project Case Studies **26**
Greenhouses **25**
Equipment/Materials **24**
Environmental **24**
Spas/Resorts **23**
Exploration **22**
Drilling **21**
Industrial Applications **21**
District Heating **21**
Electric Generation **20**
Economics **19**
Regulatory Issues **17**
Research Report **17**
Snow Melting **15**
DOE Program **14**

4. Comments

Detailed data for private home, show how to construct--keep up the good work.

I really enjoy your publication.

Great work- keep it up.

Water rights/legal options. Enjoy reading and sharing my Bulletin with others.

Good Job - I read the Bulletin cover to cover.

A great publication--getting better thru the years--Thanks!

Proof read.

Thanks!

You do a great job--sometimes too technical.

Better editing.

I encourage you to continuing to publish the GHC Quarterly Bulletin. It continues to fill an important niche.

Thanks for interesting publication.

I save every issue for reference.

Everything is great--Great publication--Keep up the good work.

Excellent publication.

I appreciate all the effort used to produce this publication. It is unique and a welcome arrival each issue.

Excellent!

Great publication!

Have been sharing your Bulletin with my environmental library all along.

Articles re: Careers in geothermal in geothermal, schools, training, internship, work study, home building.

CONCLUSIONS

We appear to be doing a good job of getting geothermal articles to the public with an emphasis on the direct-utilizations of geothermal. We will try to do a better job of editing each issues--a difficult job for an engineer as editor. We will not go to an exclusive electronic format; however as most of you realize, all issues of the Bulletin (from Vol. 16, No. 4) are available on our website. These are usually available about two weeks after publication. If you have trouble opening or downloading these, please contact Toni Boyd of our staff (boydt@oit.edu). We will also stick with our quarterly publication schedule--but would appreciate more articles from our readers.

Your requests are for more technical and general articles--we will try to provide a balanced selection of both types. We will also continue to provide international articles, as the editor feel that we can learn from experiences outside of the U.S. Geothermal heat pumps continue to be a topic of major interest, as about 25% to 30% of our inquiries for technical assistance are related to this subject. Concerning "Geothermal Resources," we do have an extensive database on geothermal wells and springs available for 16 western states. This database is available on CD-ROM and can be ordered from Donna Gibson, our office manager.

We wish to thank U.S. DOE, Office of Geothermal, for continuing to fund the Quarterly Bulletin. It has been around since 1975 with over 80 issues published during this 27-year period. We can also provide copies of back issues before Vol. 16, No. 4, upon request. Thank all of you for participating in our survey.

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